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Soil and fertilizer potassium impacts on corn and soybean grain yield, potassium uptake, and within-field grain yield variation

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Soil and fertilizer potassium impacts on corn and soybean grain yield, potassium uptake, and within-field grain yield variation

by

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CHAPTER 1: GENERAL INTRODUCTION

INTRODUCTION

Potassium is an essential nutrient needed for plant growth. Soils can provide much of the K that is needed by plants, but when supply becomes limiting, there is a need for supplemental K fertilization. Research on the effects of K fertilization for corn and soybean were studied extensively in the past. With improvements in corn hybrids and soybean varieties over the past decades, however, overall plant growth and grain yields have increased significantly and management practices also have changed since these earlier times. These changes have warranted an improvement in the understanding of K fertilization for today's crops. However, new technologies available to producers and researchers and also weakness in existing knowledge necessitates new research efforts.

The vast majority of previous field research on K management has been conducted on conventional small-plot trials with fairly homogenous initial soil-test K (STK) levels and without consideration of variation in soils, STK, and crop yield within fields. This research has resulted, for example, on STK interpretations and fertilizer recommendations. For example, current STK interpretation classes in Iowa are (in mg K kg^{-1}) ≤ 90 for Very Low, 91 to 130 for Low, 131 to 170 for Optimum, 171 to 200 for High and ≥ 201 for Very High for soil series with low subsoil K, which are the vast majority in the state. The probability of a yield response within each of these classes is 80%, 60%, 25%, 5%, and < 1%, respectively. Current recommendations suggest K fertilizer application rates to minimize K deficiencies and maintain desirable STK levels over time. However, both producers' observations and research results point to two main issues in need of research with a new focus.

Recent studies continue showing that yield responses often are observed in the low-testing STK classes and are seldom observed in soil testing Very High (> 200 mg K kg^{-1}). There is much response variation in the Optimum class, however. Furthermore, partial analyses of plant parts for K concentration in some studies suggest that K fertilization has increased the K concentration of vegetative tissues at different growth stages, often regardless of a grain yield response, but seem not to affect grain K concentration. These results are important because K uptake and redistribution to vegetative plant parts and grain greatly affect K removal from fields when different plant parts are harvested. These results also point to a need to better understand the relationships of K supply for crops (both soil K and K fertilization) on K concentrations within the plant during vegetative and reproductive growth, and how that relates to grain yield and K removal with grain harvest.

Another issue relates to the spatial variation of STK and crop response to K fertilization within fields. Many studies have shown that STK and yield levels vary considerably across the landscape within larger fields. Precision agriculture technologies such as yield monitors, global positioning systems (GPS), and geographical information systems (GIS) now are widely used in the U.S. Variable-rate application technology and soil sampling methods that georeference the sampling locations with GPS devices are available to producers and can be used for improved fertilization management. Identifying fertilizer responsive and non-responsive areas of a field is an important step in maximizing the benefits of a sound site-specific management program. However, little work has been done to assess K fertilization effects across large field areas that incorporate the influence of variation in STK and soil type. In contrast to conventional small research plots and classic on-farm strip trials in which grain from the entire length of long strips are weighed, use of these new technologies allow for study of crop responses for smaller areas along strips usually encompassing large soil-test variability, multiple soil types, and different yield levels. This methodology also can be very useful for correlating soil-test methods to grain yield responses. However, no published research has explored ways in which soil-test and yield data collected using this methodology can be used to calibrate soil-test methods.

Therefore, this research involved two different studies. The objectives of the first study were to use precision agriculture technologies adapted to a strip trial methodology to (1) assess the within-field variation of corn and soybean grain yield responses to K fertilization for several Iowa fields and (2) calibrate the ammonium-acetate STK extractant to corn and soybean grain yield responses. The objectives of the second study were to evaluate the relative magnitude of K fertilization effects on corn and soybean grain yield and both K concentration and uptake in young plants, mature leaves in summer, and grain.

DISSERTATION ORGANIZATION

This dissertation is presented as two papers suitable for publication in scientific journals of the Soil Science Society of America. The title of the first paper is “Using precision agricultural technologies to assess within-field variation of corn and soybean grain yield responses to potassium fertilization”. The title of the second paper is “Differential response of corn and soybean early growth, potassium concentration in plant tissues, and grain yield to potassium fertilization”. Each paper is divided in sections that include abstract, introduction, materials and methods, results and discussion, conclusions, reference list, and tables. The papers are preceded by a general introduction and are followed by a general conclusion.

CHAPTER 2. USING PRECISION AGRICULTURAL TECHNOLOGIES TO ASSESS WITHIN-FIELD VARIATION OF CORN AND SOYBEAN GRAIN YIELD RESPONSES TO POTASSIUM FERTILIZATION

A paper to be submitted to Soil Science Society of America Journal by

M.W. Clover and A.P. Mallarino

ABSTRACT

Precision agriculture technologies [grain yield monitors, georeferenced soil sampling, and geographical information systems (GIS)] are useful tools to study the effect of fertilization on yield and soil-test values across the landscape. A study based on one- to three-year strip-trials (63 site-years) was conducted from 2001 to 2007 in Iowa to evaluate the effects of K fertilization on corn (*Zea mays* L.) and soybean (*Glycine max* L. Merr.) grain yield and post-harvest soil-test K (STK) measured with the ammonium acetate procedure. Two K treatments (0 and 168 kg K ha^{-1}) were replicated three to four times at each site. Soil samples were collected before K application (one composite sample every 0.07 to 0.20 ha) and also from non-fertilized strips before one- and two-year trials. Potassium fertilization increased grain yield as evaluated by strip averages in 21 of 63 site-years, and only when STK of significant portions of the field tested Optimum or lower (≤ 171 mg K kg^{-1}). Yield responses for field areas testing within different STK interpretation classes showed a differential response in seven site-years with a strip-average response and in seven site-years

with no strip–average response. Study of relationships between corn and soybean grain yield response and STK showed a range of model R^2 and STK critical concentrations (CC) as a result of using linear-plateau (LP) and quadratic-plateau (QP) models and different ways of handling data collected. Determined CC by the LP model were more consistent across data handling methods and with Iowa STK interpretations, and ranged from 178 to 200 mg K kg^{-1} for corn and 155 to 246 mg K kg^{-1} for soybean. Overall, the results showed that use of traditional strip trials with sparse soil sampling and weighing along the entire length of strips often will not appropriately describe STK and yield response to fertilization. However, there was no obviously better method of handling the densely collected data for correlating yield responses to STK.

INTRODUCTION

Precision agriculture technologies such as yield monitors, differential global positioning systems (DGPS), and geographical information systems (GIS) are widely used in the U.S. for mapping soil test values, grain yield mapping, and variable-rate fertilizer applications. Many fields used in agriculture today can include a range of soil map units (SMU), ranging from one to several in a given field. Each of these SMU may have differing nutrient supplying capabilities. Many studies have shown that soil-test K (STK) levels vary considerably across the landscape within individual locations. The variation patterns are sometimes related to soil series or SMU, but fertilization, manure application, and other management practices often create new and large variability patterns at various scales (Cambardella et al., 1994; Franzen and Peck, 1995; Mallarino, 1996; Mallarino and Wittry, 2004; Sawchik and Mallarino, 2007). Historically, K fertilizer has been applied as a single, uniform rate throughout a field (Carr et al., 1991; Sawyer, 1994). However, in many cases where variation exists, the use of a single K fertilizer rate throughout a field or SMU may result in excessive fertilization in some areas and suboptimal fertilization in others (Wibawa et al., 1993; Mallarino and Wittry, 2004). Variable-rate technology allows for K application to specific areas, may improve nutrient use efficiency and farm profitability, but requires reliable and cost-effective assessments of soil-test values.

Identifying fertilizer responsive and non-responsive areas of a field is an important step in maximizing the benefits of site-specific management. Yield mapping and subsequent soil sampling often is used to identify potentially responsive and non-responsive areas within a given field (Stafford et al., 1998). Grid soil sampling is one method used where a field is divided into many smaller cells for sampling purposes to identify more variability and provide more information about soil-test levels (Wibawa et al., 1993; Rehm et al., 1996). Grid soil sampling for K in production fields is usually based on 1 ha cells (Sawyer, 1994). However, even smaller grid cells may be necessary to better account for STK variability. Research has shown that grid cell sampling at densities of 0.08 to 0.44 ha was superior to 1 ha cells at increasing accuracy of soil test mapping (Wollenhaupt et al. 1994; Franzen and Peck, 1995; Mallarino and Wittry, 2004; Sawchik and Mallarino, 2007). Because dense grid sampling is costly, zone sampling is another soil sampling method used that reduces the number of samples and sampling cost while maintaining an acceptable amount of information about nutrient variation within fields. Soil survey maps and landscape position have been used to delineate sampling zones for a long time. Yield maps also can aid zone delineation because yield can be related to nutrient availability and nutrient removal. One assumption with zone sampling is that zones based on patterns of different soil or crop characteristics need to remain temporarily stable (Franzen et al., 2000). However, several researchers have concluded that management zones based on soil survey maps may not be adequate for site-specific applications (Wollenhaupt et al. 1994; Mallarino and Wittry, 2004; Sawchik and Mallarino, 2007). One reason is that soil survey maps at scales ranging from 1:12,000 to 1:24,000, which have been used to delineate soil sampling zones for many years, have been shown to ineffective at times for site-specific management due to insufficient detail (Jaynes, 1996; Brevik et al., 2001; Mallarino and Wittry, 2004).

Potassium fertilization effects on crop grain yield have been studied for many years on small plot trials with fairly homogenous initial STK levels. Previous Iowa research (Bordoli and Mallarino, 1998; Borges and Mallarino, 2000, 2001, 2003; Bermudez et al., 2001; Mallarino et al., 2004; Barbagelata et al., 2005; Sawchik and Mallarino, 2007) showed that corn and soybean responses to K fertilizer were large and likely only when STK was in the Optimum or lower interpretation categories (< 171 mg K kg^{-1}, ammonium-acetate test, 15-cm sampling depth) as defined in Iowa (Sawyer et al, 2002). Work in Minnesota showed that yield responses on a Webster soil testing 150 mg K kg^{-1} occurred in only 3 of 14 site-years (Randall et al. 1997). Research in other regions has shown that corn responded to direct K fertilization (Vyn and Janovicek, 2001) and soybean grain yield to residual K fertilization (Yin and Vyn, 2002) when STK levels were < 100 mg K kg^{-1}. However, although many researchers have shown that STK levels can vary considerably within fields, little work has been done to assess K fertilization effects across large field areas that incorporate variation in STK and soil type. Research in Montana found that applying K fertilizer based on whole field STK levels versus STK levels of individual soil types resulted in no significant differences in wheat and barley yield (Carr et al. 1991). Sawchik and

Mallarino (2007), using a strip trial methodology, found that K fertilization increased corn and soybean grain yield based on strip averages in 8 of 11 site-years using a dense grid (0.08 to 0.27 ha) sampling method. They found that initial STK levels at each of the responsive sites testing in the low STK class ranged from 30 to 61% and in the optimum STK class from 27 to 65%. Further analyses showed that fertilization increased grain yield for areas of the field testing low in STK, but not in areas testing Optimum or higher. The authors observed a differential crop response to K fertilization in zones based on soil survey maps in only 2 of 11 site-years. They concluded that zones based on soil survey maps were less effective than grid sampling methods at assessing STK variation and yield responses to K fertilization within those site-years.

Yield monitor maps, DGPS receivers in combines, and a strip-trial methodology can be used to evaluate the effects of fertilization or other site-specific management practices (Oyarzabal et al. 1996; Bianchini and Mallarino, 2002; Wittry and Mallarino, 2004; Sawchik and Mallarino, 2007). Treatments are applied to narrow (usually the width is a multiple of the equipment used to apply the treatments) and long strips, and crops are harvested with combines equipped with yield monitors and DGPS receivers. Soil samples are collected using a dense sampling approach adapted to the strips field layout and yields are georeferenced and recorded by calibrated yield monitors. The aforementioned authors have warned about describing responses for very short distances because the yield monitor flow meters often are not reliable to resolve detailed yield variation over intervals of less than 20 to 25 m (Lark et al., 1997). In contrast to conventional small research plots and classic on-farm strip trials in which grain from the entire length of long strips are weighed, use of this technology allows for study of crop responses for smaller areas along strips usually encompassing large soil-test variability, multiple soil types, and different yield levels. This methodology also can be very useful for correlating soil-test methods to grain yield responses. However, no published research has explored ways in which soil-test and yield data collected using this methodology can be used to calibrate soil-test methods. Therefore, the objectives of this study were to use precision agriculture technologies adapted to a strip trial methodology to (1) assess the within-field variation of corn and soybean grain yield responses to K fertilization for several Iowa fields and (2) calibrate the ammonium-acetate STK extractant to corn and soybean grain yield responses.

MATERIALS AND METHODS

Sites, Soil Sampling, and Treatments

Replicated strip trials were conducted during 7 years on 37 Iowa farmer's fields managed with corn-soybean and corn-corn rotations. At each field, approximately 2 to 7 ha located at least 40 m away from field borders were selected to establish the trials. Table 1 shows information about the experimental areas and the two dominant soil series according to digitized, 1:12000 scale survey maps. The soil series were typical soils of Iowa and border regions of several states. Fields 1, 6, 12, 13, 21, and 23 were managed with no-till, and all other fields were managed with chisel-plow/disk tillage. Other management practices were those used by each farmer and, therefore, corn hybrids, soybean varieties, seeding rates, and planting dates varied among fields.

Treatments were a control without K fertilization and K fertilization using a high, non-limiting but not excessive rate of 186 kg K ha^{-1}, applied as potassium chloride (KCl, 0-0-

52 N-P-K). These two treatments were applied to alternating long strips at each site to accommodate four replications in most fields (three replications were used at Sites 2 and 6). The strip width was uniform at each field but ranged from 9.1 m at Site 1 to 27.4 m at Sites 24 and 25. Strip length was uniform at each field but varied from 183 to 640 m across fields. Measurements were made with a measuring tape, permanent markers were placed at each trial corner, and coordinates were recorded with a hand-held GPS receiver. The experiments were evaluated from one to three years at each site. Cropping sequences at two- and three-year sites were corn-soybean rotations, with the exception of Fields 14, 18, and 28, which were in continuous corn. Fertilizer was applied in the fall after harvest (October or November) or in the spring (March) before planting. Fertilizers were incorporated into the soil by disking, with the exception of Fields 1, 6, 12, 13, 21, and 23 that were managed with no-till. Suffixes “a”, “b”, and “c” in the code used for each site-year for Fields 1 through 37 indicate the first, second, and third crop at that field, and suffixes “b_2” and “c_2” denote when fertilizer was reapplied prior to that site-year. Hereon, the combination of field and crop (site-year) will be referred to as a site.

Composite soil samples (15-cm depth) were collected from each site before applying treatments using a dense grid-point sampling approach adapted to the experimental layout. Before applying treatments for the first time, the separation of the grid lines across strips coincided with the width of each replication (two strips), and the separation along strips was 45.7 m at Site 11 and 36.6 m at all other sites (grid cell size was 0.07 to 0.20 ha). Soil cores (8-12) for each composite sample were collected from the entire area (following no specific pattern) of a circle approximately 100 m^2 in size at the center of each cell, and the center of the circle was georeferenced as a sample point. Before applying treatments for a second time (i.e., before the second crop), soil samples were collected from the non-fertilized strips to be able to relate yield response of crops from the second site-year to soil-test values of these non-fertilized strips. Sampling methods and cell length were similar to those used for the first sampling data. Soil samples were analyzed for STK with the ammonium-acetate test following methods suggested for the North-Central Region (Warnke and Brown, 1998). Iowa STK interpretation classes (Sawyer et al., 2002) were used in this study. The classes for STK are (in mg K kg^{-1}) ≤ 90 for Very Low, 91 to 130 for Low, 131 to 170 for Optimum, 171 to 200 for High and ≥ 201 for Very High for soil series with low subsoil K, which are the vast majority in the state. The interpretation classes for the series with higher subsoil K levels involve lower STK values.

Grain Yield Measurements

Grain yield was harvested with farm combines equipped with impact flow-rate yield monitors and DGPS receivers using differential correction from the U.S. Coast Guard AM beacon transmitter. The yield monitors were calibrated by weighing grain harvest along combine passes outside the experimental areas. A sensor located in the grain augers measured grain moisture, and yield was adjusted to moisture contents of 155 g kg^{-1} for corn and 130 g kg^{-1} for soybean. Yield data used for the study were unaffected by borders because experimental areas were at least 40 m away from field borders and data from combine passes that included border rows between strips were not used. One or two combine passes (two passes for 4.57 and 6.1 m grain platforms and one pass for 7.62, 9.14, and 10.67 m grain platforms) were used from each soybean strip, and two 6.1 m to four 4.57m wide combine passes were used from each corn strip. Yield monitor data were imported into

ArcView GIS (Environmental Systems Research Inst. Inc., Redlands, CA), and analyzed for any common yield monitor problems (Mallarino et al., 2001) such as effects of waterways or unplanned combine stops, and affected data were deleted.

Evaluation of Yield Response to Fertilization and Soil-Test K Calibration

Grain yield responses to K fertilization were assessed using three procedures. Procedure 1 assessed the grain yield response to fertilization over the experimental area of each site was assessed by ANOVA assuming a RCBD using PROC MIXED of SAS, in which fertilization was considered a fixed effect and replication (blocks) was considered a random effect. Yield inputs were means of all yield monitor points recorded at 1-s intervals within each treatment strip. For analysis of treatment effects on yield for areas within fields, yield responses were assessed by procedures 2 and 3. Procedure 2 analyzed treatment effects on yield for field areas testing within Iowa STK interpretation classes by a procedure developed by Oyarzabal et al. (1996) and Bianchini and Mallarino (2002), which was more recently used by Sawchik and Mallarino (2007). Yield input data were means for the grid cells defined by the width of each treatment strip and the separation distance of the soils sampling grid lines. The STK input data of analyses for the first-year crops were values from soil samples collected from the entire experimental area before the first K application and for subsequent site-years were values from samples collected from the control strips. Yield means for both the control and fertilized treatments corresponded to one initial STK value. To assess the consistency of treatment effects for field areas testing within different STK classes for each crop and field, we used an ANOVA procedure (PROC MIXED of SAS). Fertilization, STK class, and the fertilization by STK class interaction were considered fixed effects while replication (blocks) was considered a random effect. Procedure 3 used similar data management and ANOVA to test treatment effects for different soil series. Yield data for areas encompassed by each treatment, replication, and soil series from digitized soil-survey maps at a 1:12000 scale (Iowa Cooperative Soil Survey, 2002) were averaged using ArcView. Values were not used for these two procedures when there were less than three yield cells for any STK class or soil series.

Segmented linear-plateau and quadratic-plateau models used before to correlate soil-test methods to yield response from conventional small plots were used to correlate STK to corn and soybean yield response. There is no clearly superior or widely accepted method for defining critical concentration (CC) values or ranges (Dahnke and Olson, 1990; Mallarino and Blackmer, 1992). Others have found it useful to define CC ranges on the basis of values identified by the linear-plateau and quadratic-plateau models (Mallarino and Atia, 2005; Dodd and Mallarino, 2005). These models were fit with the Nonlinear Models (NLIN) procedure of SAS (SAS Inst., 2000), and CC were defined as the STK values at which the two portions of each model joined. The models were fit to different sets of data (pairs of STK and yield response values) to estimate of CC across all sites in four different ways. Procedure 1 used the STK and yield response data for the smallest area for which STK and yield response were estimated (the individual 0.07 to 0.20 ha cells). Therefore there were as many pairs of observations (STK and yield response data) at each site-year as numbers of soil sampling cells. Relative yield response was calculated for each cell by dividing the yield for the control treatment by the yield of the fertilized treatment and multiplying by 100. Procedure 2 related average STK and relative yield response at each site (one pair of observations per site). Procedure 3 used averages for each dominant soil series at each site using similar calculations (one or more pairs of observation at each site depending on the number of dominant soil series). Finally, Procedure 4 calculated mean STK and yield responses according to three yield classes at each site (High, Medium, and Low). The yields for each individual cell in an individual site-year were ranked from lowest yielding to highest yielding and yields were arbitrarily assigned to the three classes (≤ 33%, 34 to 65%, and ≥ 66%. The matching STK values also were averaged. Therefore there were three pairs of observations at each site. Relative crop yield for Procedures 2, 3, and 4 were calculated by dividing the corresponding mean of the control by the mean of the fertilized treatment and multiplying by 100.

RESULTS AND DISCUSSION

Whole Field Responses

Potassium fertilization increased ($P \leq 0.10$) corn grain yield at 13 sites (Sites 1a, 3a, 6a, 9a, 10b, $11b_2$, 12a, 13a, 18a, 23a, 25a, 28a, and $29b_2$) and soybean grain yield at eight sites (Sites 3b, 4a, 11a, 11c, 23b, 24a, $33b_2$, 34a) (Table 3). Comparisons of yield responses and initial STK values suggest that the results for the responsive sites in general were reasonable because mean STK at most sites were within the Very Low, Low, or Optimum interpretation classes (Table 2). The probability of yield response to K fertilization for these classes is 80%, 60%, and 25%, respectively (Sawyer et al., 2002). Mean initial STK values for the responsive sites ranged from a low of 89 mg K kg^{-1} for Site 6a to a high of 194 mg K ha^{-1} for Site $33b_2$. The proportion of STK values representing each interpretation class at each responsive site ranged from 0% to 38% for the Very Low class, 0% to 83% for the Low class, and 6% to 72% for the Optimum class. Overall, the proportion of STK values measured at each responsive site within these three classes ranged from 33% to 100%.

There were many sites that initially tested Low and Optimum (Table 2) where no grain yield response was observed (Table 3). For example, no grain yield response was observed at Site 18b (corn, a second-year trial) and Site 13b (soybean, a second-year trial), but responses occurred in the first year for both fields. The STK of the control strips before these second-year crops were Low at Site 18b (125 mg K kg^{-1}) and Very Low at Site 13b (84 mg K kg^{-1}). It is important to note that while the grain yield responses in relation to initial STK levels were expected, a lack of yield response in some low-testing soils should be expected. A large yield response at Sites 10b and $33b_2$ was not expected because the mean initial STK levels for those sites in those years were 182 mg K ha^{-1} and 194 mg K ha^{-1}, respectively. While these mean STK levels were in the High STK class, however, the distribution of STK levels showed that approximately 47% and 33% of the area of the strips not receiving K fertilizer tested within the Optimum STK class for Sites 10b and $33b_2$, respectively, which may explain this response. Potassium fertilization seemed to have resulted in a yield decrease in two soybean sites (Sites 9b and $19c_2$). The response at these sites was small and inconsistent with previous years' results, however. We believe the negative response this year was probably a random effect because the broadcast K rates applied should not decrease crop yield.

The results of this portion of the study agree with other research done on both small-plot trials and large field strip-trials. Sawchik and Mallarino (2007) found that K fertilization increased corn and soybean grain yields at 8 of 11 sites in Iowa. The distribution of STK values at those sites into the interpretation classes ranged from 20 to 67% in the Low class and 27 to 65% in the Optimum class. Other published work done in Iowa on small plots showed that K fertilization was likely to increase grain yield when initial STK levels were < mg K kg^{-1} using the same K test used in this study (Bordoli and Mallarino, 1998; Borges and Mallarino, 2000, 2001, 2003; Mallarino et al., 2004; Barbagelata et al., 2005).

Crop Responses in Field Areas with Different Soil-Test K Values

Analyses of corn yield response for field areas that tested within different Iowa STK interpretation classes showed that yield response to K differed ($P \leq 0.10$) between classes at Sites 1a, 4b, 6a, 12a, 14a, 14b, and 23a (Table 4). The yield response differed between the STK classes only when classes for which a response is likely (Very Low, Low, or Optimum classes) were included at a site. The whole-field results and the study by STK classes coincided in showing a corn response to K at Sites 1a, 6a, 12a, and 23a. Observed responses at Sites 6a (including Very Low and Low classes), 12a (including Low, Optimum, and High classes), and 23a (including Low and Optimum Classes) were similar in that responses were highest for the lowest testing classes at each of these sites and decreased with increasing STK class. Responses at Site 1a (including Low, Optimum, High and Very High classes) were highest for the Low, Optimum, and High testing classes, and lowest for the Very High class. However, the crop response to K differed between STK classes for Sites 4b, 14a, and 14b even though results for the whole-field analysis indicated no response to K at these sites. Responses at Site 4b were highest for the Optimum class (1.68 Mg ha^{-1}) and smallest for the Low and Very High classes. We do not understand a lower response for the Low class than for the Optimum class. Responses at Sites 14a and 14b were highest for the Very Low (14a) and Low (14b) classes, which is expected, and decreased with increasing STK for both.

Analysis of soybean yield data showed that yield responses to K differed between STK classes at Sites 2a, 11a, $19c_2$, 20b, 23b, 24a, and $27b_2$ (Table 4). Results for Sites 11a, 23b, and 24a coincided with the results for the strip-average analysis and indicated a yield response in those fields. Yield responses at Sites 11a and 24a were highest for the Very Low (11a) and Low (24a) testing classes, and decreased with increasing STK levels. At Site 23b, however, which included only the classes Low and Optimum, the yield responses were highest for the Optimum class (0.62 Mg ha^{-1}) and lower for the Low testing class (0.46 Mg ha^{-1}). The crop response to K differed among STK classes for Sites 2a, 20b, and $27b_2$, although the strip-average analysis showed no response. Yield responses at Site 2a were highest for the Optimum class and there was a slight decrease in yield for the Very High testing class. A statistically different crop response to K for among STK classes at Sites 20b and $27b_2$ is unexpected because it is explained by small apparent decreases in yield due to K fertilization in the Very High testing class for both sites.

Results from the analyses of yield response to K fertilization according to the STK interpretation classes present in each field were useful for various reasons. First, they showed that with few exceptions the ranking of the yield responses were within expectations, that is there were larger responses for the low-testing classes and smaller or no responses for the high and very high testing classes. Second, they clearly showed how results from a few composite soil samples collected across a large field area might result in inaccurate assessments of crop-available soil K and wrong fertilizer recommendations. Finally, a few unexpected results also demonstrated that a significant level of error exists from soil testing and field yield evaluations even when the sampling density is much higher than what is done and may be afforded in production agriculture.

Crop Responses in Field Areas with Different Soil Series

Because of imposed replication requirements, analyses of yield response to K for field areas with different soil series were not done for all years of Fields 2, 16, 19, 20, and 21 because only one dominant soil series encompassed more than one field replication. Also, this analysis could not be conducted for Site 29a because due to a yield monitor problem only whole strip averages could be recorded. Analysis of yield response data from the other sites showed that K fertilization differed among the soil series at eight of 31 corn sites and four of 22 soybean sites (Table 5). General characteristics and typical profile descriptions of soil series present in fields included in the study can be found online (Iowa Cooperative Soil Survey, 2001).

Fields at five corn sites (Sites 1a, 14a, 14c, 15a, and 35a) and the soybean Site 11c were conducted on soils of the Clarion-Nicollet-Webster soil association, although the soils or the proportion of area of each soil in the experimental areas differed (Table 5). Additional soils included at those sites were Canisteo (Sites 14a, 14c, 15a), Okoboji (Sites 14a, 14c), Crippin (Site 11c), and Clarion-Storden and Terril (Site 35a). Potassium fertilization increased grain yield on the Clarion soil at Sites 1a, 11c, 14c, and 35a, and on the Nicollet soil at Sites 1a, 11c, 14a, and 14c. Responses for other dominant soil series were less frequent, with responses on the Canisteo soil at Sites 11c and 14a, Webster at Sites 1a and 15a, and Terril at Site 35a. At some sites, initial STK levels explained this difference in responses. For example, K fertilization increased grain yield at Site 14c on both the Clarion and Nicollet soils, but not on the Canisteo, Okoboji, or Webster soils. Initial soil-test K levels for both the Clarion and Nicollet soils were 90 and 114 mg K kg^{-1}, respectively, as compared to the higher levels in the Canisteo, Okoboji, and Webster soils (127, 149, and 177 mg K kg^{-1}, respectively). Results at Site 11c showed that a soybean yield response to K application occurred on all soils but the Crippin soil. A possible explanation for this response difference may be that Crippin soils are calcareous. Previous research has shown that soybean yield on Iowa calcareous soils can be lower than in non-calcarous soils (Rogovska et al., 2007; Sawchik and Mallarino, 2008) and this might have limited the soybean response to K fertilizer. The differences in yield responses to K fertilization between soils at Sites 1a, 15a, and 35a were variable and inconsistent across the sites, and there is no clear explanation for the differential responses. All soils of this association formed on loam glacial till, but the Clarion series occupies higher and steeper landscape positions and is better drained than the Nicollet series, and much better drained than the Canisteo, Webster, and Okoboji series, which are found in low topographic positions. Speculation about reasons for different response to K other than due to different STK levels is risky because the soils differ in many other properties.

Analysis of yield response data for soil series of fields located in soil associations other than the Clarion-Nicollet-Webster association showed that K fertilization differed among the soil series at three corn sites (Sites 12a, 30a, and 37a) and three soybean sites (Sites 24a, 30b_2, and 36a) (Table 5). Results at site 24a showed that soybean responded to K fertilization on the Waukee and Raddle soils, but not on the Koszta soil. Comparison of initial STK levels for these soils showed that on average Waukee and Raddle soils tested within the Low and lower Optimum classes, respectively, while the Koszta soil tested within the upper level of the Optimum class. Results at Site 12a showed that there was a corn yield response on the Klinger-Maxfield soil, but not on the Clyde-Floyd or Dinsdale soils, but STK did not explain the differential response and reasons for the difference cannot be determined.

A statistically different crop response to K for among soil types at Sites 30a, $30b_2$, 36a, and 37a is unexpected because it is explained by small apparent decreases in yield due to K fertilization in the Galva soil for Sites 30a and 30b, the Ackmore–Colo soil complex at Site 36a, and the Tama soil at Site 37a. None of these yield decreases is logical, however, and the analysis of strip averages showed a small yield decrease due to K fertilization only for two soybean sites. Neither the literature nor our experience with corn and soybean in Iowa suggest a logical reason for a yield decrease to K fertilization for the rates, application method, and STK levels in this study. Spurious negative corn and soybean responses to fertilization occasionally are observed for conventional small-plot trials and strip trials, and often cannot be explained.

Calibration of Yield Responses to Soil-Test K

Models that were fit and calculated STK CC across corn or soybean sites corresponding to four methods of handling STK and yield response data (Cell, Site, Soil Series, and Yield Level) are shown in Table 6. The fit of LP and QP models always was statistically significant and resulted in different CC values regardless of the crop or classification method used. Previous research showed that different models can result in large differences in fertilizer rates that determine maximum yield or CC when fit to the same data set (Cerrato and Blackmer, 1990; Mallarino and Blackmer, 1992; Mallarino and Blackmer, 1994; Dodd and Mallarino, 2005; Mallarino and Atia, 2005). Furthermore, Dahnke and Olson (1990), Mallarino and Blackmer (1992), and Cox (1996) discussed implications of these differences for fertilizer recommendations and the profitability of fertilization. In this study, however, we used the CC determined by these two models with the primary objective of comparing different ways of handling soil-test and yield response data from strip trials managed with dense soil sampling, GPS, and yield monitors. An obviously larger CC range defined by the two models for soybean sites than for corn sites should not be expected. We believe this difference is explained by less clearly defined relationships for soybean, regardless of the method of analysis, but especially fewer soybean sites with intermediate and high STK values. This was especially obvious for the method based on site averages, when there were only two soybean sites with STK higher than about 200 mg K kg^{-1} but several for corn.

Results for the analysis that used all individual cells across all sites indicated that the CC determined by the LP and QP models were 197 and 242 mg K kg^{-1} for corn, and 246 and 351 mg K kg^{-1} for soybean, respectively (Table 6). When we used averages by site, the CC for corn were 200 and 233 mg K kg^{-1} (LP and QP, respectively), and the CC for soybean were 201 and 273 mg K kg^{-1} (LP and QP, respectively). When we used averages by soil series, the CC for corn were 178 and 209 mg K kg^{-1} with LP and QP models, respectively, and for soybean were 155 and 208 mg K kg^{-1} with LP and QP models, respectively. When we used averages by three levels of yield, the CC for corn were 197 and 242 mg K kg^{-1} with LP and QP models, respectively, and for soybean were 228 and 374 mg K kg^{-1} with LP and QP models, respectively.

Comparisons of relationships between STK and grain yield response for the different data classification methods and the calculated CC showed some interesting points. Comparing the R^2 values for the models indicate that in spite of high statistical significance in all instances (Table 6), there was much more variability for the method that used individual small cells compared to the other three methods. In fact, the method using the highest level of data averaging (site averages) resulted in the highest R^2 values. This difference is best observed in Figs. 1 through 4. Lower R^2 values for the cell methods were the result of including more observations and also more variable relationships between STK and yield response. One could hypothesize that using pairs of STK and yield response values from small areas (without being too small so the response estimate using yield monitors still is reliable) should result in better relationships. However, very large small-scale variability in both soil-test values and yield demonstrated in previous research (Mallarino, 1996; Mallarino et al., 2001; Mallarino and Wittry, 2004) may result in much random noise that may not reflect well underlying relationships.

Observation of the distribution of points for the method based on averages by soil series (Fig. 3) and yield levels (Fig. 4) indicate no consistent trend differences due to soil series or yield level. Study of relationships between yield response and STK within each soil series and yield level within a site and across sites (not shown) did not show clear or consistent differences, and study of the subsoil K classification of the series did not help either. Perhaps this lack of clear effect of soil series and yield level on relationships and CC in the study was the result of not having enough observations within a site to be able to detect differences. However, we speculate that the reason is that the soils and yield levels in the study actually do not result in different relationships and CC for STK, because the study of yield responses by soil series did not show consistent differences either. Furthermore, previous Iowa crop response research with K (Bordoli and Mallarino, 1998; Borges and Mallarino, 2000, 2001, 2003; Bermudez et al., 2001; Mallarino et al., 2004; Barbagelata et al., 2005; Sawchik and Mallarino, 2007) did not show consistent differences due to soil series or yield levels.

The distribution of observations in the figures and CC (Table 6) determined by the LP model for corn (which seemed less affected by few observations in some STK ranges) were almost identical for the data management methods by individual cell, site averages, and yield level averages (197 to 200 mg K kg^{-1}) but was slightly lower for averages by soil series (178 mg K kg^{-1}). For soybean, however, the determined CC by the LP model for cell, site averages, and yield level averages ranged from 201 to 246 mg K kg^{-1}, which might be explained by reasons suggested before, but as in corn the CC for averages by soil series was the lowest (155 mg K kg^{-1}). When considering results for both crops, the CC determined with the LP model for the methods using site averages or averages by soil series were more consistent with yield responses observed in the analysis by STK class, and were more similar to results of previous K research in Iowa. Corn and soybean yield responses seldom were observed in soils with STK higher than about 200 mg K kg^{-1} when research was conducted using conventional small-plot trials (Bordoli and Mallarino, 1998; Borges and Mallarino, 2000, 2001, 2003; Mallarino et al., 2004; Barbagelata et al., 2005) or strip trials (Bermudez et al., 2001; Sawchik and Mallarino, 2007). The better balanced STK data for the corn sites do suggest that as long as a study includes a wide and balanced range of STK values and many fields, different methods of handling data collected from strip trials do not result in CC differences greater than that found when different models are used to correlate soil-test values and yield responses collected using conventional small-plot trials.

SUMMARY AND CONCLUSIONS

Potassium fertilization increased grain yield as evaluated by strip averages in 21 of 63 site-years, and only when STK of significant portions of the field was in the Optimum or lower STK interpretation classes as they are currently defined in Iowa (≤ 171 mg K kg^{-1}). Analysis of yield responses for field areas testing within different STK interpretation classes showed a differential response in seven of the 21 site-years where strip averages show a response, and in seven site-years not identified as responsive by strip averages. With very few exceptions, this portion of the study confirmed larger and more likely responses in the low testing interpretation classes than in the Optimum, oR high-testing classes. Results also demonstrated the value of dense soil sampling and evaluations of yield response within fields, because in several fields there as no average yield response but there were yield responses in low-testing field areas. In contrast, analysis of yield responses for soil series within a field showed no consistent differences between soils, and the few occasions in which the yield response differed within a field the difference was explained by the average STK level or we could not find a reasonable explanation.

Study of relationships between corn and soybean grain yield response and STK showed a range of model R^2 and CC as a result of using two models and different ways of handling data collected with dense soil sampling, GPS, and yield monitors. The LP and QP models used defined a much larger CC range for soybean sites than for corn sites, which was explained by larger variability regardless of the method of data analysis fewer soybean sites with intermediate and high STK values. The CC determined by the LP model for corn (which was less affected by few observations in some STK ranges) were almost identical for data management methods using by individual cells, site averages, and yield level averages

(197 to 200 mg K kg^{-1}) and was slightly lower for averages by soil series (178 mg K kg^{-1}). For soybean, however, the CC determined by these methods ranged from 201 to 246 mg K kg^{-1}, but as in corn the CC for averages by soil series was the lowest (155 mg K kg^{-1}). When considering results for both crops, the CC determined with the LP model for the methods based on site averages or averages by soil series were more consistent with yield responses observed in the analysis by STK class and more similar to results of previous K research in Iowa. The better balanced data for corn suggest that as long as a study include a wide and balanced range of STK values and many fields, different methods of handling data collected from strip trials do not result in CC differences greater than that found when different models are used to correlate soil-test values and yield responses collected using conventional small-plot trials.

Overall, the results showed that STK variability and resulting yield responses to K fertilization within and across fields is highly variable. Use of dense soil sampling in combination with a strip trial methodology adapted to precision agricultural technologies proved useful to assess crop yield responses in different parts of a field with varying levels of STK. The study demonstrated that use of traditional strip trials methods with sparse soil sampling and weighing along the entire length of strips often will not appropriately describe soil-test values and crop yield response to fertilization. However, there was obviously no better method of handling the densely collected data for correlating yield responses to soil-test values.

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Table 1. Location, area, predominant soil series, and soil pH for experimental areas in 37 fields.

			Dominant Soil			Second Dominant Soil			
Site	County	Area† ha	Series	Classification	Area‡ %	Series§	Classification	Area %	pH
1	Greene	2.41	Clarion	Typic Hapludolls	44	Webster	Typic Endoaquolls	33	5.7
2	Marshall	2.41	Killduff	Dystric Eutrudepts	100	-	-	-	7.2
3	Black Hawk	4.28	Nevin	Pachic Argiudolls	53	Lawler	Aquic Hapludolls	25	5.8
4	Black Hawk	4.28	Saude	Typic Hapludolls	59	Wiota	Pachic Argiudolls	41	5.4
5	Calhoun	4.82	Clarion	Typic Hapludolls	78	Webster	Typic Endoaquolls	22	5.8
6	Marshall	2.41	Spillville	Cumulic Hapludolls	100	-	-	-	6.5
7	Story	5.62	Webster	Typic Endoaquolls	36	Nicollet	Aquic Hapludolls	33	7.0
8	Story	4.99	Clarion	Typic Hapludolls	50	Webster	Typic Endoaquolls	50	6.4
9	Calhoun	4.28	Nicollet	Aquic Hapludolls	78	Clarion	Typic Hapludolls	22	6.7
10	Calhoun	4.28	Canisteo	Typic Endoaquolls	56	Webster	Typic Endoaquolls	28	6.4
11	Dallas	7.02	Nicollet	Aquic Hapludolls	43	Canisteo	Typic Endoaquolls	24	6.4
12	Linn	4.28	Dinsdale	Typic Argiudolls	56	Klinger-Maxfield	Aquic Hapludolls	25	6.7
13	Buchanan	4.82	Kenyon	Typic Hapludolls	53	Readlyn	Aquic Hapludolls	33	6.0
14	Story	4.28	Webster	Typic Endoaquolls	38	Canisteo	Typic Endoaquolls	31	7.1
15	Greene	4.28	Clarion	Typic Hapludolls	63	Webster	Typic Endoaquolls	28	6.5
16	Grundy	2.01	Tama	Typic Argiudolls	100	-	-	-	7.2
17	Marshall	3.21	Killduff	Dystric Eutrudepts	54	Colo-Ely	Cumulic Hapludolls	46	6.8
18	Marshall	4.28	Killduff	Dystric Eutrudepts	84	Tama	Typic Argiudolls	16	7.2
19	Marshall	4.28	Tama	Typic Argiudolls	100	-	-	-	6.6
20	Carroll	3.75	Calco	Cumulic Endoaquolls	100	-	-	-	8.1
21	Jasper	3.75	Otley	Oxyaquic Argiudolls	100	-	-	-	6.5
22	Pocahontas	4.28	Nicollet	Aquic Hapludolls	38	Webster	Typic Endoaquolls	38	6.7
23	Jefferson	4.28	Taintor	Vertic Argiaquolls	88	Mahaska	Aquic Argiudolls	13	7.4
24	Iowa	7.22	Koszta	Udollic Endoaqualfs	72	Raddle	Typic Hapludolls	17	5.8
25	Iowa	7.22	Sparta	Entic Hapludolls	47	Jackson	Typic Hapludalfs	19	7.6
26	Henry	4.28	Ladoga	Mollic Hapludalfs	50	Givin	Udollic Endoaqualfs	38	6.1
27	Henry	4.82	Otley	Oxyaquic Argiudolls	69	Nira	Oxyaquic Hapludolls	22	6.2
28	Cedar	4.82	Klinger	Aquic Hapludolls	69	Franklin	Udollic Endoaqualfs	17	7.0

† Size of the experimental area at each field.

‡ Percentage of the experimental area with that soil series.

§ Two series names indicate a soil complex was mapped, and the classification is for the first (dominant) series.

Table 1. (continued)

Site	County	Area†	Dominant Soil			Second Dominant Soil			pH
			Series	Classification	Area‡	Series§	Classification	Area	
		ha			%			%	
29	O'Brien	4.82	Galva	Typic Hapludolls	50	Primghar	Aquic Hapludolls	33	5.8
30	O'Brien	4.82	Galva	Typic Hapludolls	44	Primghar	Aquic Hapludolls	39	5.1
31	Marshall	4.82	Muscatine	Aquic Hapludolls	64	Garwin	Typic Endoaquolls	19	6.8
32	Cedar	5.71	Klinger	Aquic Hapludolls	59	Garwin	Typic Endoaquolls	25	6.4
33	Boone	6.42	Canisteo	Typic Endoaquolls	31	Nicollet	Aquic Hapludolls	28	6.9
34	Boone	6.42	Webster	Typic Endoaquolls	33	Nicollet	Aquic Hapludolls	25	6.2
35	Story	4.82	Clarion	Typic Hapludolls	39	Terril	Cumulic Hapludolls	22	-
36	Jasper	4.82	Killduff	Dystric Eutrudepts	69	Tama	Typic Argiudolls	22	7.4
37	Jasper	4.82	Muscatine	Aquic Hapludolls	78	Tama	Typic Argiudolls	22	7.1

Table 2. Descriptive statistics for soil-test K and classification into Iowa State University interpretation classes for all sites before fertilizer application the first year and for all subsequent year's control plots.

		Descriptive Statistics			Field Area for Five Soil-Test Classes§				
Site†	Year	Mean	Median	SD‡	VL	L	Opt	H	VH
		--------------mg K kg^{-1}---------			-------------------------%----------------------				
1a	2004	168	157	39	0	19	39	22	19
1b	2005	155	151	37	0	33	36	17	14
2a	2002	283	269	104	0	0	22	0	78
3a	2004	121	126	36	28	31	31	9	0
3b	2005	106	106	42	38	44	9	9	0
4a	2004	163	125	122	0	63	28	0	9
4b	2005	165	137	116	0	44	41	0	16
5a	2004	152	148	31	0	31	42	19	8
5b	2005	140	143	25	3	28	61	8	0
6a	2002	89	77	31	28	33	6	11	22
7a	2004	203	194	61	0	0	31	33	36
8a	2004	204	193	51	0	3	22	28	47
9a	2003	171	174	18	0	0	47	44	9
9b	2004	167	167	14	0	0	59	41	0
10a	2003	159	153	30	0	19	50	19	13
10b	2004	182	174	40	0	0	47	38	16
11a	2002	108	110	12	10	83	7	0	0
11b_2	2003	133	133	21	0	48	52	0	0
11c	2004	126	125	18	0	62	38	0	0
12a	2005	143	144	25	0	38	47	16	0
13a	2004	112	112	16	11	75	14	0	0
13b	2005	84	83	15	61	39	0	0	0
14a	2002	137	108	100	19	59	9	0	13
14b	2003	162	152	61	0	31	47	9	13
14c	2004	144	135	63	3	41	44	0	13
15a	2005	153	147	38	0	16	63	16	6
15b	2006	133	130	35	0	50	47	0	3
16a	2002	180	178	27	0	0	33	47	20
16b	2003	161	157	23	0	0	80	20	0
17a	2002	104	102	14	17	83	0	0	0
17b	2003	136	130	24	0	50	33	17	0
18a	2002	111	110	18	9	78	13	0	0
18b	2003	125	126	15	0	56	44	0	0
19a	2002	187	164	65	0	9	50	13	28
19b	2003	189	170	65	0	0	59	13	28
19c_2	2004	196	166	64	0	0	59	9	31

† Suffixes "a", "b", and "c" in the site code identify the first, second, and third crop at a given location. The suffixes "b_2" and "c_2"indicates that treatments were reapplied before the start of that crop year.

‡ Standard Deviation

§ Soil-test K interpretation classes: VL, Very Low; L, Low; Opt, Optimum; H, High; VH, Very High (Sawyer et al., 2002).

Table 2. (continued)

		Descriptive Statistics			Field Area for Five Soil-Test Classes§				
Site†	Year	Mean	Median	SD‡	VL	L	Opt	H	VH
		--------------mg K kg^{-1}---------			-------------------------%----------------------				
20a	2003	176	179	35	0	11	32	36	21
20b	2004	172	181	33	0	14	25	50	11
21a	2001	294	261	118	0	0	13	13	75
22a	2005	205	185	64	0	9	25	25	41
23a	2004	139	140	15	0	28	72	0	0
23b	2005	130	131	11	0	47	53	0	0
24a	2007	155	154	46	0	36	22	28	14
25a	2007	120	108	53	19	64	8	0	8
26a	2006	201	195	31	0	0	16	41	44
26b	2007	172	166	27	0	0	53	31	16
27a	2006	196	185	45	0	0	17	50	33
27b	2007	154	151	23	0	11	69	19	0
28a	2006	136	134	15	0	39	61	0	0
28b_2	2007	142	133	32	0	42	47	0	11
29a	2006	212	208	29	0	0	0	36	64
29b_2	2007	172	168	24	0	0	64	28	8
30a	2006	255	238	97	0	0	0	0	100
30b_2	2007	203	185	87	0	0	0	78	22
31a	2007	323	315	52	0	0	0	0	100
32a	2007	188	181	35	0	0	38	34	28
33a	2006	213	213	49	0	0	28	8	64
33b_2	2007	194	195	49	0	0	33	31	36
34a	2006	163	158	30	0	14	47	28	11
34b_2	2007	154	155	28	0	31	36	33	0
35a	2006	158	148	42	0	19	53	11	17
35b_2	2007	133	130	35	0	53	33	14	0
36a	2007	175	171	18	0	0	47	44	8
37a	2007	172	173	25	0	8	39	44	8

† Suffixes "a", "b", and "c" in the site code identify the first, second, and third crop at a given location. The suffixes "b_2" and "c_2"indicates that treatments were reapplied before the start of that crop year.

‡ Standard Deviation

§ Soil-test K interpretation classes: VL, Very Low; L, Low; Opt, Optimum; H, High; VH, Very High (Sawyer et al., 2002).

Table 3. Mean corn and soybean grain yield as affected by K fertilization across the entire strip length of each treatment.

			Treatment		
Site†	Year	Crop	Control	Fertilized	Statistics
			----------Mg ha^{-1}-----------		*P* > *F*
1a	2004	Corn	13.18	13.81	0.01
1b	2005	Soybean	4.14	4.07	0.21
2a	2002	Soybean	4.99	4.98	0.88
3a	2004	Corn	10.20	10.90	0.05
3b	2005	Soybean	3.10	3.43	0.02
4a	2004	Soybean	3.89	4.14	0.09
4b	2005	Corn	10.87	11.46	0.23
5a	2004	Corn	13.23	13.63	0.24
5b	2005	Soybean	4.35	4.42	0.29
6a	2002	Corn	9.95	11.86	0.01
7a	2004	Soybean	3.97	3.95	0.49
8a	2004	Soybean	3.30	3.31	0.31
9a	2003	Corn	9.56	10.16	0.01
9b	2004	Soybean	3.04	2.98	0.04
10a	2003	Soybean	2.19	2.26	0.18
10b	2004	Corn	11.66	12.10	0.07
11a	2002	Soybean	3.48	3.79	0.03
11b_2	2003	Corn	11.28	12.26	0.01
11c	2004	Soybean	3.85	4.12	0.02
12a	2005	Corn	8.92	9.35	0.02
13a	2004	Corn	12.22	12.81	0.01
13b	2005	Soybean	2.64	2.71	0.38
14a	2002	Corn	11.50	12.27	0.23
14b	2003	Corn	11.30	12.18	0.21
14c	2004	Corn	10.10	10.45	0.22

† Suffixes "a", "b", and "c" in the site code identify the first, second, and third crop at a given location. The suffixes "b_2" and "c_2"indicates that treatments were reapplied before the start of that crop year.

Table 3. (continued)

Site†	Year	Crop	Treatment Control	Fertilized	Statistics
			----------Mg ha^{-1}-----------		$P > F$
15a	2005	Corn	10.88	11.53	0.21
15b	2006	Soybean	3.46	3.54	0.32
16a	2002	Corn	10.17	10.01	0.65
16b	2003	Corn	13.21	13.80	0.34
17a	2002	Soybean	3.76	3.83	0.22
17b	2003	Corn	11.80	11.93	0.81
18a	2002	Corn	11.31	11.77	0.06
18b	2003	Corn	9.82	10.39	0.25
19a	2002	Soybean	4.47	4.54	0.28
19b	2003	Corn	13.16	13.48	0.17
$19c_2$	2004	Soybean	3.68	3.62	0.05
20a	2003	Corn	11.62	11.59	0.90
20b	2004	Soybean	3.67	3.82	0.26
21a	2001	Corn	11.15	11.22	0.12
22a	2005	Corn	11.45	11.43	0.82
23a	2004	Corn	11.00	11.72	0.03
23b	2005	Soybean	2.18	2.73	0.01
24a	2007	Soybean	4.52	4.63	0.02
25a	2007	Corn	12.55	13.26	0.02
26a	2006	Soybean	3.71	3.60	0.20
$26b_2$	2007	Corn	13.81	13.71	0.27
27a	2006	Corn	12.03	12.07	0.75
$27b_2$	2007	Soybean	3.32	3.20	0.57
28a	2006	Corn	13.75	14.17	0.05
$28b_2$	2007	Corn	11.57	12.26	0.22
29a	2006	Soybean	4.12	4.14	0.92
$29b_2$	2007	Corn	10.54	10.89	0.05

Table 3. (continued)

Site†	Year	Crop	Treatment Control	Treatment Fertilized	Statistics
			----------Mg ha^{-1}-----------		*P* > *F*
30a	2006	Corn	11.95	11.85	0.18
30b$_2$	2007	Soybean	3.94	3.92	0.78
31a	2007	Corn	12.48	13.00	0.37
32a	2007	Corn	13.27	13.57	0.35
33a	2006	Corn	11.70	11.76	0.85
33b$_2$	2007	Soybean	4.22	4.34	0.03
34a	2006	Soybean	3.37	3.46	0.09
34b$_2$	2007	Corn	12.23	12.16	0.62
35a	2006	Corn	10.99	11.28	0.26
35b$_2$	2007	Soybean	3.59	3.70	0.33
36a	2007	Soybean	4.64	4.93	0.16
37a	2007	Corn	12.49	12.69	0.14

Table 4. Corn and soybean grain yield as affected by K fertilization for field areas with different soil-test K classes.

Site†	Year	Crop	STK class‡	Treatment		Statistics		
				Control	Fertilized	K	STK	K x STK§
				--------Mg ha^{-1}--------		-----------------*P* > *F*------------		
1a	2004	Corn	L	12.82	13.43	0.01	0.37	0.08
			Opt	13.27	14.02			
			H	13.08	13.87			
			VH	13.48	13.74			
1b	2005	Soybean	L	3.89	3.89	0.19	0.01	0.53
			Opt	4.22	4.10			
			H	4.33	4.29			
			VH	4.30	4.17			
2a	2002	Soybean	Opt	4.98	5.13	0.44	0.26	0.08
			VH	4.99	4.93			
3a	2004	Corn	VL	10.29	11.05	0.07	0.34	0.91
			L	10.43	11.10			
			Opt	9.62	10.23			
3b	2005	Soybean	VL	2.02	2.35	0.01	0.01	0.76
			L	3.67	4.06			
			Opt	3.76	4.11			
			H	4.36	4.47			
4a	2004	Soybean	L	3.79	4.09	0.30	0.37	0.28
			Opt	3.99	4.25			
			VH	4.26	4.10			
4b	2005	Corn	L	10.88	10.88	0.10	0.11	0.01
			Opt	9.76	11.44			
			VH	13.19	12.89			
5a	2004	Corn	L	12.96	13.63	0.24	0.90	0.42
			Opt	13.27	13.63			
			H	13.47	13.55			
			VH	13.42	13.74			
5b	2005	Soybean	L	4.06	4.36	0.23	0.02	0.18
			Opt	4.41	4.38			
			H	4.73	4.80			

† Suffixes "a", "b", and "c" in the site code identify the first, second, and third crop at a given location. The suffixes "b_2" and "c_2"indicates that treatments were reapplied before the start of that crop year.

‡ STK Classes: VL, Very Low; L, Low; Opt, Optimum; H, High; VH, Very High (Sawyer et al., 2002).

§ Probability of the interaction between K fertilization and STK classes for each site.

Table 4. (continued)

Site†	Year	Crop	STK class‡	Treatment Control	Treatment Fertilized	Statistics K	Statistics STK	Statistics K x STK§
				--------Mg ha^{-1}--------		-----------------$P > F$------------		
6a	2002	Corn	VL	9.39	11.75	0.01	0.01	0.05
			L	10.94	11.96			
7a	2004	Soybean	Opt	4.11	4.07	0.68	0.32	0.60
			H	3.93	3.98			
			VH	3.87	3.80			
8a	2004	Soybean	Opt	3.35	3.34	0.94	0.33	0.29
			H	3.37	3.31			
			VH	3.21	3.28			
9a	2003	Corn	Opt	9.66	10.43	0.01	0.12	0.23
			H	9.47	9.98			
			VH	9.48	9.65			
9b	2004	Soybean	Opt	3.08	3.02	0.09	0.29	0.93
			H	2.98	2.92			
10a	2003	Soybean	L	2.20	2.23	0.11	0.49	0.46
			Opt	2.17	2.24			
			H	2.23	2.34			
			VH	2.16	2.24			
10b	2004	Corn	Opt	11.66	12.19	0.07	0.80	0.28
			H	11.65	12.13			
			VH	11.65	11.78			
11a	2002	Soybean	VL	3.14	4.02	0.01	0.62	0.02
			L	3.50	3.76			
			Opt	3.81	4.05			
$11b_2$	2003	Corn	L	11.24	12.09	0.01	0.29	0.11
			Opt	11.32	12.43			
11c	2004	Soybean	L	3.88	4.17	0.01	0.22	0.46
			Opt	3.82	4.03			
12a	2005	Corn	L	8.27	9.27	0.76	0.62	0.04
		Corn	Opt	9.14	9.41			
		Corn	H	10.28	9.26			
13a	2004	Corn	VL	12.25	12.74	0.01	0.01	0.45
			L	12.11	12.77			
			Opt	12.71	13.13			
13b	2005	Soybean	VL	2.62	2.70	0.41	0.46	0.79
			L	2.67	2.73			

Table 4. (continued)

Site†	Year	Crop	STK class‡	Treatment		Statistics		
				Control	Fertilized	K	STK	K x STK§
				--------Mg ha^{-1}--------		-----------------$P > F$------------		
14a	2002	Corn	VL	10.77	12.05	0.22	0.00	0.10
			L	11.59	12.22			
			Opt	11.90	12.62			
			VH	12.32	12.94			
14b	2003	Corn	L	11.40	12.68	0.30	0.32	0.05
			Opt	11.15	12.06			
			H	11.48	12.46			
			VH	11.44	11.01			
14c	2004	Corn	VL	10.21	11.72	0.11	0.19	0.30
			L	9.81	10.46			
			Opt	10.12	10.24			
			VH	10.96	10.86			
15a	2005	Corn	L	10.57	11.13	0.17	0.53	0.88
			Opt	10.88	11.56			
			H	10.88	11.73			
15b	2006	Soybean	L	3.39	3.52	0.23	0.11	0.15
			Opt	3.52	3.57			
16a	2002	Corn	Opt	10.19	10.06	0.67	0.74	0.85
			H	10.15	9.92			
			VH	10.16	10.08			
16b	2003	Corn	Opt	13.12	13.76	0.40	0.18	0.55
			H	13.59	13.96			
17a	2002	Soybean	VL	3.71	3.80	0.45	0.67	0.94
			L	3.77	3.84			
17b	2003	Corn	L	11.44	11.86	0.92	0.35	0.47
			Opt	12.10	11.92			
			H	12.27	12.17			
18a	2002	Corn	VL	11.94	12.28	0.02	0.34	0.39
			L	11.30	11.71			
			Opt	10.90	11.98			
18b	2003	Corn	L	9.38	10.11	0.19	0.01	0.14
			Opt	10.35	10.74			
19a	2002	Soybean	L	4.40	4.59	0.20	0.85	0.17
			Opt	4.45	4.56			
			H	4.52	4.56			
			VH	4.51	4.48			
19b	2003	Corn	Opt	13.12	13.56	0.16	0.87	0.40
			H	13.09	13.40			
			VH	13.27	13.34			

Table 4. (continued)

Site†	Year	Crop	STK class‡	Treatment: Control	Treatment: Fertilized	Statistics: K	Statistics: STK	Statistics: K x STK§
				--------Mg ha^{-1}--------		-----------------$P > F$------------		
19c$_2$	2004	Soybean	Opt	3.69	3.63	0.45	0.09	0.04
			H	3.65	3.72			
			VH	3.65	3.57			
20a	2003	Corn	L	12.44	13.06	0.78	0.49	0.44
			Opt	11.25	11.43			
			H	11.70	11.58			
			VH	11.97	11.56			
20b	2004	Soybean	L	3.80	3.78	1.00	0.31	0.02
			Opt	3.48	3.51			
			H	3.74	4.09			
			VH	3.67	3.31			
21a	2001	Corn	Opt	10.98	10.92	0.49	0.27	0.61
			H	10.94	11.09			
			VH	11.21	11.30			
22a	2005	Corn	L	11.37	11.57	0.95	0.97	0.54
			Opt	11.51	11.39			
			H	11.54	11.36			
			VH	11.37	11.45			
23a	2004	Corn	L	10.99	11.99	0.01	0.36	0.08
			Opt	11.01	11.62			
23b	2005	Soybean	L	2.17	2.63	0.01	0.13	0.02
			Opt	2.19	2.82			
24a	2007	Soybean	L	4.33	4.70	0.80	0.69	0.03
			Opt	4.62	4.68			
			H	4.56	4.61			
			VH	4.80	4.43			
25a	2007	Corn	VL	12.07	13.14	0.16	0.39	0.90
			L	12.49	13.16			
			Opt	14.16	14.62			
			VH	12.42	12.64			
26a	2006	Soybean	Opt	3.80	3.73	0.22	0.01	0.58
			H	3.73	3.62			
			VH	3.65	3.54			
26b$_2$	2007	Corn	Opt	13.89	13.70	0.75	0.80	0.14
			H	13.76	13.66			
			VH	13.61	13.83			

Table 4. (continued)

Site†	Year	Crop	STK class‡	Treatment Control	Treatment Fertilized	Statistics K	Statistics STK	Statistics K x STK§
				--------Mg ha^{-1}--------		------------------$P > F$------------		
27a	2006	Corn	Opt	12.11	12.30	0.72	0.35	0.14
			H	11.98	12.13			
			VH	12.05	11.87			
$27b_2$	2007	Soybean	L	3.69	3.81	0.35	0.01	0.01
			Opt	3.34	3.29			
			H	2.72	1.96			
28a	2006	Corn	L	13.67	14.11	0.05	0.05	0.72
			Opt	13.80	14.20			
$28b_2$	2007	Corn	L	11.15	12.01	0.36	0.10	0.32
			Opt	11.63	12.36			
			VH	12.70	12.64			
$29b_2$	2007	Corn	Opt	10.56	10.99	0.08	0.57	0.34
			H	10.48	10.70			
			VH	10.52	10.62			
$30b_2$	2007	Soybean	H	3.93	3.92	0.58	0.97	0.35
			VH	3.97	3.89			
32a	2007	Corn	Opt	13.17	13.74	0.38	0.62	0.76
			H	13.61	13.69			
			VH	12.82	13.09			
33a	2006	Corn	Opt	11.89	11.82	0.83	0.32	0.23
			H	11.86	11.58			
			VH	11.60	11.75			
$33b_2$	2007	Soybean	Opt	4.36	4.45	0.01	0.11	0.41
			H	4.20	4.39			
			VH	4.06	4.14			
34a	2006	Soybean	L	3.48	3.53	0.01	0.01	0.28
			Opt	3.54	3.60			
			H	3.23	3.29			
			VH	2.68	2.98			
$34b_2$	2007	Corn	L	12.37	12.17	0.60	0.46	0.58
			Opt	12.14	12.12			
			H	12.17	12.17			
35a	2006	Corn	L	9.91	10.36	0.18	0.01	0.73
			Opt	11.02	11.28			
			H	11.48	11.96			
			VH	12.14	12.19			

Table 4. (continued)

Site†	Year	Crop	STK class‡	Treatment			Statistics	
				Control	Fertilized	K	STK	K x STK§
				--------Mg ha^{-1}--------		------------------$P > F$------------		
35b$_2$	2007	Soybean	L	3.41	3.65	0.72	0.05	0.25
			Opt	3.75	3.75			
			H	3.96	3.84			
36a	2007	Soybean	Opt	4.58	4.87	0.24	0.18	0.81
			H	4.66	4.98			
			VH	4.94	5.03			
37a	2007	Corn	L	12.52	12.81	0.36	0.38	0.15
			Opt	12.15	12.69			
			H	12.75	12.71			
			VH	12.64	12.41			

Table 5. Corn and soybean grain yield as affected by K fertilization for field areas with different soil series.

					Treatment		Statistics		
Site†	Year	Crop	Soil Series	STK‡	Control	Fertilized	K	Soil Series	K x Soil Series§
					--------Mg ha^{-1}--------		------------------------*P* > *F*--------------------------		
1a	2004	Corn	Clarion	145	13.00	13.76	0.01	0.57	0.04
			Nicollet	191	13.41	13.71			
			Webster	183	13.29	13.97			
1b	2005	Soybean	Clarion	138	3.99	3.97	0.15	0.03	0.57
			Nicollet	180	4.19	4.06			
			Webster	161	4.29	4.22			
3a	2004	Corn	Lawler	87	10.72	11.55	0.05	0.04	0.58
			Nevin	136	9.77	10.32			
			Saude	125	10.01	10.73			
3b	2005	Soybean	Lawler	67	1.52	1.97	0.01	0.01	0.11
			Nevin	124	3.65	4.04			
			Saude	106	3.36	3.44			
4a	2004	Soybean	Saude	171	3.76	4.05	0.06	0.04	0.62
			Wiota	151	4.08	4.29			
4b	2005	Corn	Saude	180	10.26	10.77	0.28	0.07	0.74
			Wiota	144	11.80	12.57			
5a	2004	Corn	Clarion	146	13.16	13.62	0.30	0.54	0.34
			Webster	176	13.49	13.65			
5b	2005	Soybean	Clarion	136	4.23	4.29	0.38	0.01	0.92
			Webster	155	4.60	4.69			

† Suffixes "a", "b", and "c" in the site code identify the first, second, and third crop at a given location. The suffixes "b_2" and "c_2"indicates that treatments were reapplied before the start of that crop year.

‡ Initial STK of the control plots within each soil type for that site-year.

§ Probability of the interaction between K fertilization and soil series for each site.

Table 5. (continued)

Site†	Year	Crop	Soil Series	STK‡	Treatment: Control	Treatment: Fertilized	Statistics: K	Statistics: Soil Series	Statistics: K x Soil Series§
					--------Mg ha^{-1}--------		----------------------$P > F$----------------------		
7a	2004	Soybean	Canisteo	252	3.65	3.51	0.43	0.05	0.51
			Clarion	147	4.35	4.23			
			Nicollet	189	3.88	3.92			
			Webster	230	3.96	3.99			
8a	2004	Soybean	Clarion	190	3.24	3.25	0.69	0.03	0.99
			Webster	217	3.36	3.37			
9a	2003	Corn	Clarion	156	9.21	10.01	0.01	0.16	0.32
			Nicollet	175	9.66	10.20			
9b	2004	Soybean	Clarion	157	3.07	2.97	0.07	0.92	0.52
			Nicollet	170	3.03	2.98			
10a	2003	Soybean	Canisteo	165	2.17	2.24	0.13	0.63	0.39
			Clarion	123	2.21	2.23			
			Webster	166	2.20	2.29			
10b	2004	Corn	Canisteo	199	11.71	12.11	0.04	0.85	0.82
			Clarion	144	11.50	11.98			
			Webster	168	11.64	12.15			
11a	2002	Soybean	Canisteo	113	3.27	3.64	0.05	0.01	0.36
			Clarion	99	3.49	3.93			
			Crippin	113	3.12	3.20			
			Nicollet	109	3.67	3.95			
$11b_2$	2003	Corn	Canisteo	144	11.49	12.59	0.01	0.01	0.52
			Clarion	114	10.98	11.78			
			Crippin	158	12.08	12.88			
			Nicollet	129	11.09	12.16			

Table 5. (continued)

Site†	Year	Crop	Soil Series	STK‡	Treatment: Control	Treatment: Fertilized	Statistics: K	Statistics: Soil Series	Statistics: K x Soil Series§
					--------Mg ha^{-1}--------		------------------------$P > F$--------------------------		
11c	2004	Soybean	Canisteo	138	3.74	4.06	0.01	0.08	0.07
			Clarion	109	3.70	4.19			
			Crippin	143	3.79	3.86			
			Nicollet	123	4.00	4.19			
12a	2005	Corn	Clyde-Floyd	153	11.92	12.36	0.02	0.01	0.09
			Dinsdale	138	7.99	8.07			
			Klinger-Maxfield	146	8.79	10.11			
13a	2004	Corn	Clyde-Floyd	97	12.32	12.84	0.02	0.78	0.88
			Kenyon	115	12.24	12.83			
			Readlyn	113	12.13	12.79			
13b	2005	Soybean	Clyde-Floyd	66	2.40	2.54	0.25	0.01	0.15
			Kenyon	90	2.63	2.74			
			Readlyn	82	2.76	2.74			
14a	2002	Corn	Canisteo	112	11.08	12.11	0.21	0.02	0.01
			Clarion	101	11.65	12.42			
			Nicollet	90	10.96	12.18			
			Okoboji	122	12.25	12.11			
			Webster	184	11.78	12.45			
14b	2003	Corn	Canisteo	135	11.05	12.22	0.19	0.03	0.42
			Clarion	115	12.06	13.55			
			Nicollet	152	10.71	11.48			
			Okoboji	161	11.90	11.75			
			Webster	195	11.47	12.27			
14c	2004	Corn	Canisteo	127	9.73	10.12	0.10	0.36	0.01
			Clarion	90	10.26	11.73			
			Nicollet	114	9.44	11.01			
			Okoboji	149	10.64	9.58			
			Webster	177	10.42	10.62			

Table 5. (continued)

Site†	Year	Crop	Soil Series	STK‡	Treatment		Statistics		
					Control	Fertilized	K	Soil Series	K x Soil Series§
					--------Mg ha^{-1}--------		------------------------*P* > *F*--------------------------		
15a	2005	Corn	Canisteo	167	10.71	11.64	0.10	0.73	0.05
			Clarion	150	11.08	11.46			
			Webster	155	10.49	11.66			
15b	2006	Soybean	Canisteo	132	3.56	3.55	0.49	0.58	0.59
			Clarion	134	3.47	3.56			
			Webster	129	3.41	3.51			
17a	2002	Soybean	Colo-Ely	101	3.74	3.82	0.37	0.78	0.94
			Killduff	106	3.77	3.85			
17b	2003	Corn	Colo-Ely	148	11.73	11.89	0.82	0.78	0.93
			Killduff	125	11.86	11.97			
18a	2002	Corn	Killduff	113	11.23	11.67	0.06	0.07	0.84
			Tama	99	11.75	12.25			
18b	2003	Corn	Killduff	122	9.64	10.29	0.33	0.01	0.11
			Tama	143	10.80	10.95			
22a	2005	Corn	Clarion	184	11.16	11.49	0.93	0.66	0.28
			Nicollet	213	11.41	11.38			
			Okoboji	187	11.69	11.34			
			Webster	209	11.46	11.48			
23a	2004	Corn	Mahaska	136	10.72	11.15	0.03	0.01	0.11
			Taintor	140	11.04	11.80			
23b	2005	Soybean	Mahaska	125	2.24	2.70	0.01	0.92	0.39
			Taintor	131	2.17	2.73			
24a	2007	Soybean	Koszta	166	4.59	4.59	0.01	0.74	0.01
			Raddle	132	4.42	4.72			
			Waukee	122	4.25	4.77			

Table 5. (continued)

Site†	Year	Crop	Soil Series	STK‡	Treatment		Statistics		
					Control	Fertilized	K	Soil Series	K x Soil Series§
					--------Mg ha^{-1}--------		------------------------$P > F$--------------------------		
25a	2007	Corn	Humeston	178	11.24	13.99	0.01	0.06	0.18
			Jackson	130	13.43	14.26			
			Koszta	108	14.17	15.13			
			Sparta	108	12.06	12.45			
			Wiota	120	12.89	13.14			
26a	2006	Soybean	Givin	189	3.74	3.63	0.24	0.01	0.71
			Ladoga	207	3.67	3.56			
			Taintor	210	3.76	3.69			
26b$_2$	2007	Corn	Givin	160	13.76	13.65	0.20	0.62	0.46
			Ladoga	178	13.80	13.76			
			Taintor	184	13.99	13.66			
27a	2006	Corn	Mahaska	175	12.07	11.82	0.74	0.69	0.54
			Nira	208	12.10	12.13			
			Otley	195	12.00	12.08			
27b$_2$	2007	Soybean	Mahaska	133	3.50	3.37	0.51	0.08	0.75
			Nira	155	2.87	2.65			
			Otley	156	3.37	3.31			
28a	2006	Corn	Dinsdale	152	13.93	14.29	0.07	0.03	0.72
			Franklin	138	13.66	14.00			
			Klinger	133	13.74	14.18			
28b$_2$	2007	Corn	Dinsdale	184	12.69	12.91	0.31	0.02	0.28
			Franklin	128	11.35	11.66			
			Klinger	137	11.32	12.20			
29b	2007	Corn	Galva	179	10.51	10.87	0.04	0.47	0.88
			Marcus	159	10.32	10.74			
			Primghar	168	10.69	10.99			

Table 5. (continued)

Site†	Year	Crop	Soil Series	STK‡	Treatment: Control	Treatment: Fertilized	Statistics: K	Statistics: Soil Series	Statistics: K x Soil Series§
					--------Mg ha^{-1}--------		------------------------$P > F$--------------------------		
30a	2006	Corn	Galva	283	11.92	11.60	0.64	0.22	0.01
			Marcus	229	11.88	12.10			
			Primghar	234	12.01	12.01			
30b$_2$	2007	Soybean	Galva	223	3.85	3.72	0.87	0.01	0.01
			Marcus	193	4.07	4.09			
			Primghar	184	3.97	4.04			
31a	2007	Corn	Garwin	273	11.46	12.28	0.36	0.01	0.53
			Muscatine	347	12.73	13.23			
			Tama	291	12.68	12.95			
32a	2007	Corn	Dinsdale	187	14.20	14.29	0.40	0.01	0.82
			Garwin	208	11.46	11.98			
			Klinger	180	13.64	13.92			
33a	2006	Corn	Canisteo	227	11.63	11.80	0.76	0.01	0.28
			Clarion	162	11.74	11.62			
			Harps	241	11.30	11.61			
			Nicollet	198	12.04	11.92			
			Okoboji	291	11.40	11.63			
33b$_2$	2007	Soybean	Canisteo	208	4.20	4.40	0.01	0.01	0.24
			Clarion	139	4.34	4.46			
			Harps	219	3.63	3.77			
			Nicollet	182	4.48	4.49			
			Okoboji	265	3.77	3.96			
34a	2006	Soybean	Canisteo	196	2.71	3.01	0.06	0.01	0.30
			Clarion	134	3.55	3.63			
			Nicollet	147	3.46	3.46			
			Webster	174	3.38	3.48			

Table 5. (continued)

Site†	Year	Crop	Soil Series	STK‡	Treatment: Control	Treatment: Fertilized	Statistics: K	Statistics: Soil Series	Statistics: K x Soil Series§
					--------Mg ha^{-1}--------		------------------------$P > F$------------------------		
34b$_2$	2007	Corn	Canisteo	183	11.99	12.04	0.67	0.01	0.94
			Clarion	139	12.51	12.48			
			Nicollet	139	12.14	12.00			
			Webster	156	12.24	12.13			
35a	2006	Corn	Clarion	145	10.99	11.48	0.42	0.01	0.01
			Clarion-Storden	124	9.33	9.02			
			Nicollet	187	10.69	10.84			
			Terrril	168	11.10	11.68			
			Webster	178	11.82	11.79			
35b$_2$	2007	Soybean	Clarion	123	3.54	3.81	0.75	0.01	0.35
			Clarion-Storden	100	3.09	3.04			
			Nicollet	128	3.76	3.72			
			Terrril	139	3.65	3.66			
			Webster	166	3.80	3.84			
36a	2007	Soybean	Ackmore-Colo	181	4.81	4.60	0.39	0.01	0.06
			Killduff	174	4.56	4.90			
			Tama	175	4.80	5.14			
37a	2007	Corn	Muscatine	175	12.47	12.81	0.91	0.09	0.01
			Tama	163	12.55	12.25			

Table 6. Linear-plateau (LP) and quadratic-plateau (QP) models fit to relationships between relative yields and soil-test K across sites for several data management methods.

Method	Crop	N‡	Model	Equation§	$P > F$	R^2	CC¶
							mg K kg^{-1}
Cell	Corn	1078	QP	$y = -0.0003x^2 + 0.2x + 79.2$	<0.01	0.11	242
			LP	$y = 0.07x + 85.6$	<0.01	0.11	197
	Soybean	760	QP	$y = -0.0002x^2 + 0.1x + 82.6$	<0.01	0.12	351
			LP	$y = 0.07x + 86.1$	<0.01	0.12	246
Site	Corn	37	QP	$y = -0.0005x^2 + 0.2x + 71.2$	<0.01	0.51	233
			LP	$y = 0.08x + 83.5$	<0.01	0.49	200
	Soybean	27	QP	$y = -0.0002x^2 + 0.1x + 86.2$	0.03	0.27	273
			LP	$y = 0.05x + 90.0$	0.02	0.28	201
Soil Series	Corn	106	QP	$y = -0.0005x^2 + 0.2x + 76.6$	<0.01	0.27	209
			LP	$y = 0.07x + 85.8$	<0.01	0.26	178
	Soybean	72	QP	$y = -0.0005x^2 + 0.2x + 77.6$	<0.01	0.18	208
			LP	$y = 0.1x + 82.6$	<0.01	0.19	155
Yield Level	Corn	111	QP	$y = -0.0004x^2 + 0.2x + 76.3$	<0.01	0.31	242
			LP	$y = 0.08x + 84.6$	<0.01	0.3	197
	Soybean	81	QP	$y = -0.0002x^2 + 0.1x + 82.9$	<0.01	0.21	374
			LP	$y = 0.07x + 85.6$	<0.01	0.22	228

† Data management method: Cell, individual 0.07 to 0.20 ha cell; Site, average across all cells; Soil Series, average across all cells; Yield Level, average across all cells within each field (see Methods section)..

‡ Number of points used to determine RY relationship with STK.

§ Equation shown applies only for X values less than values at which the two portions of the models join.

¶ Critical concentration of STK determined by the models.

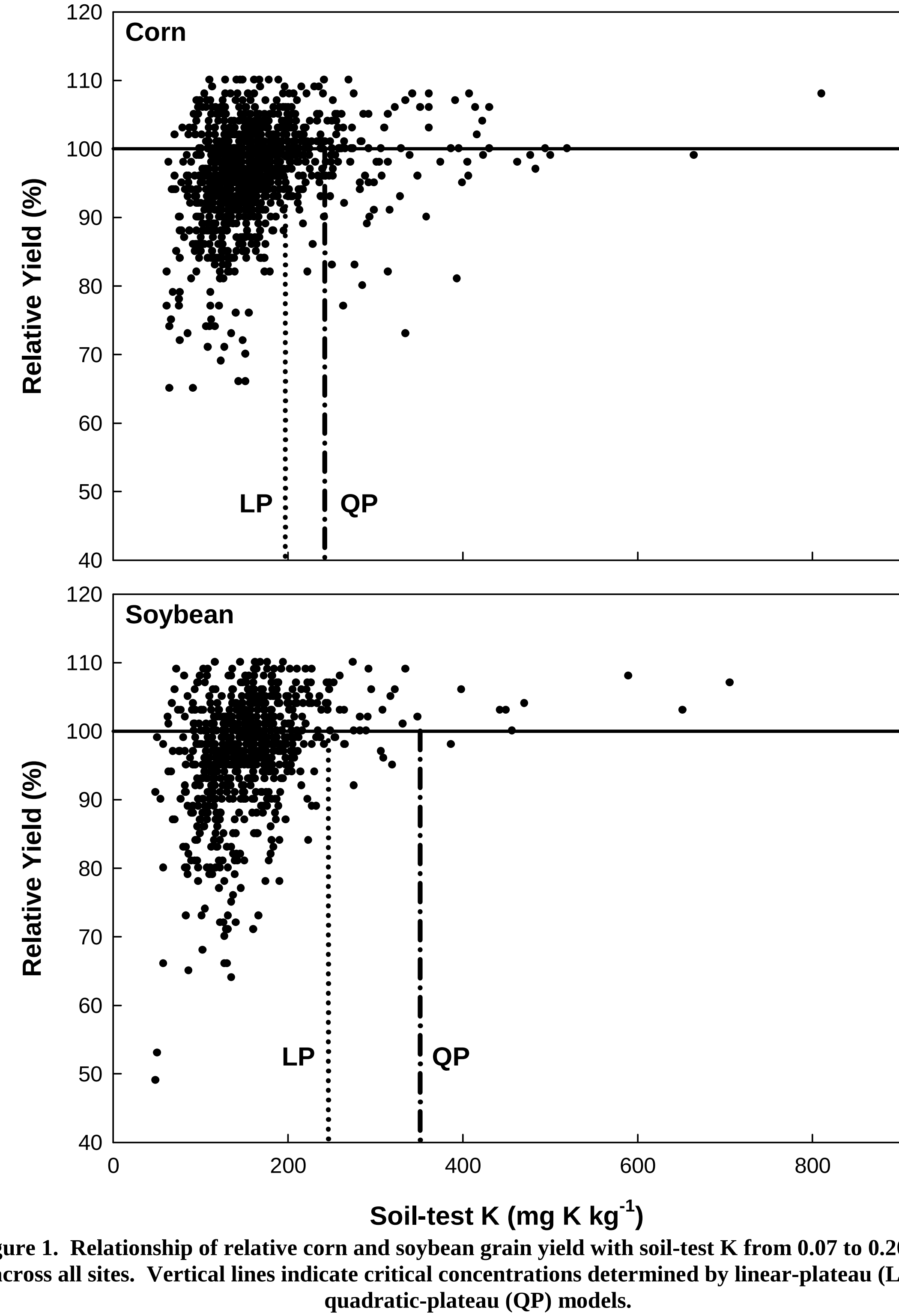

Figure 1. Relationship of relative corn and soybean grain yield with soil-test K from 0.07 to 0.20 ha cells across all sites. Vertical lines indicate critical concentrations determined by linear-plateau (LP) and quadratic-plateau (QP) models.

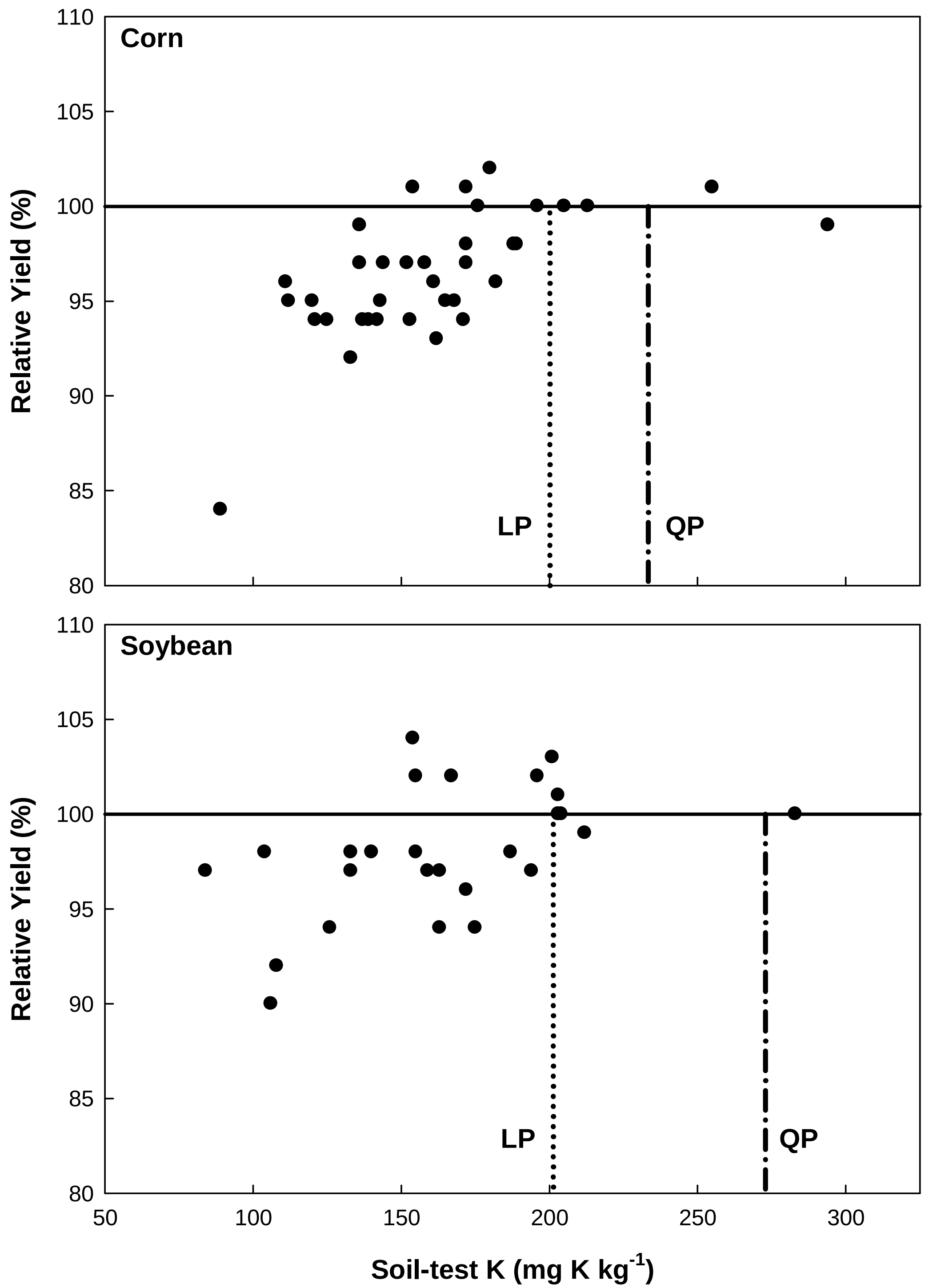

Figure 2. Relationship of relative corn and soybean grain yield with soil-test K across all sites for averages of data from individual cells at each site. Vertical lines indicate critical concentrations determined by linear-plateau (LP) and quadratic-plateau (QP) models.

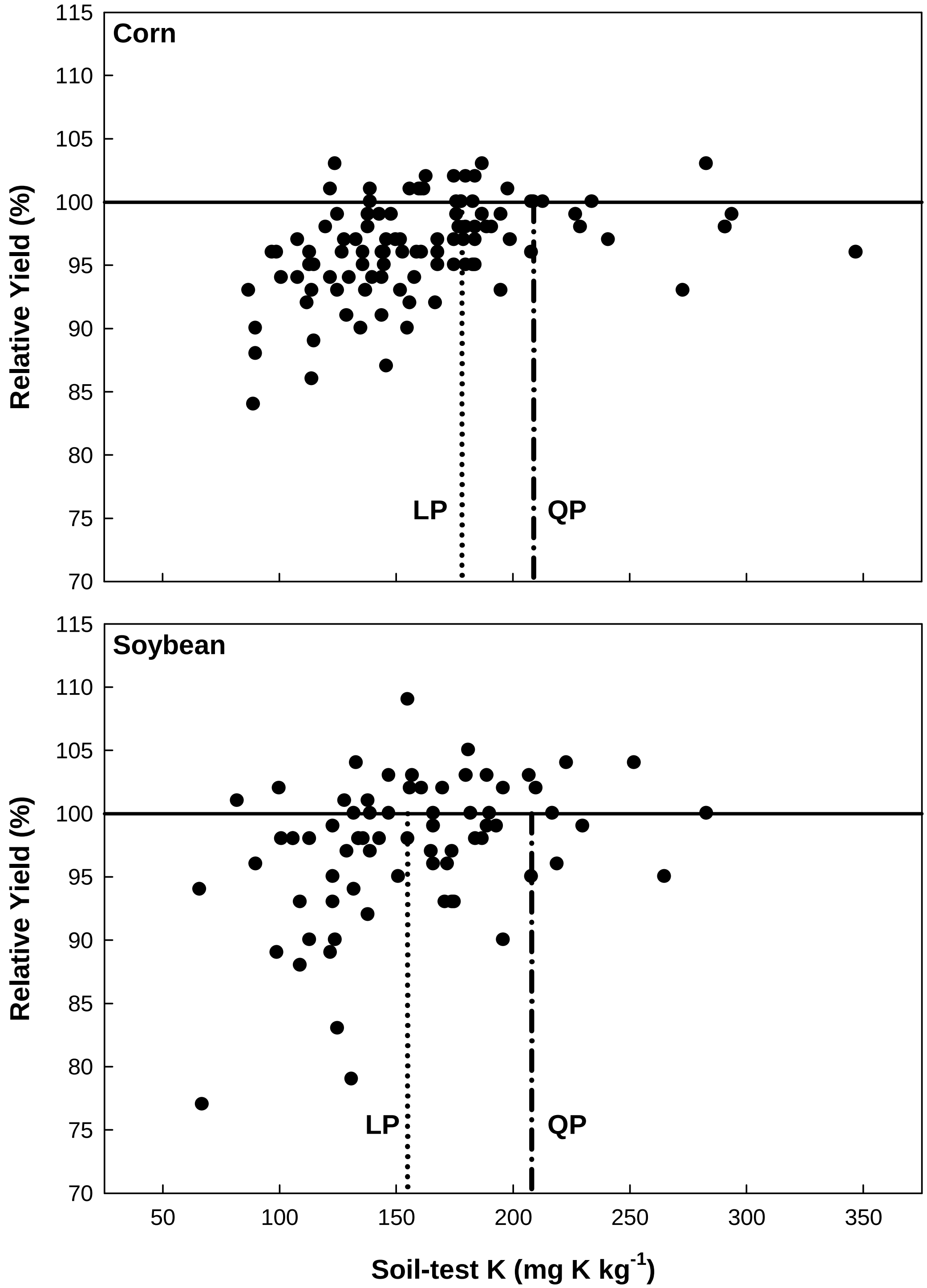

Figure 3. Relationship of relative corn and soybean grain yield with soil-test K across all sites for averages of individual cells within each soil series at each site. Vertical lines indicate critical concentrations determined by linear-plateau (LP) and quadratic-plateau (QP) models.

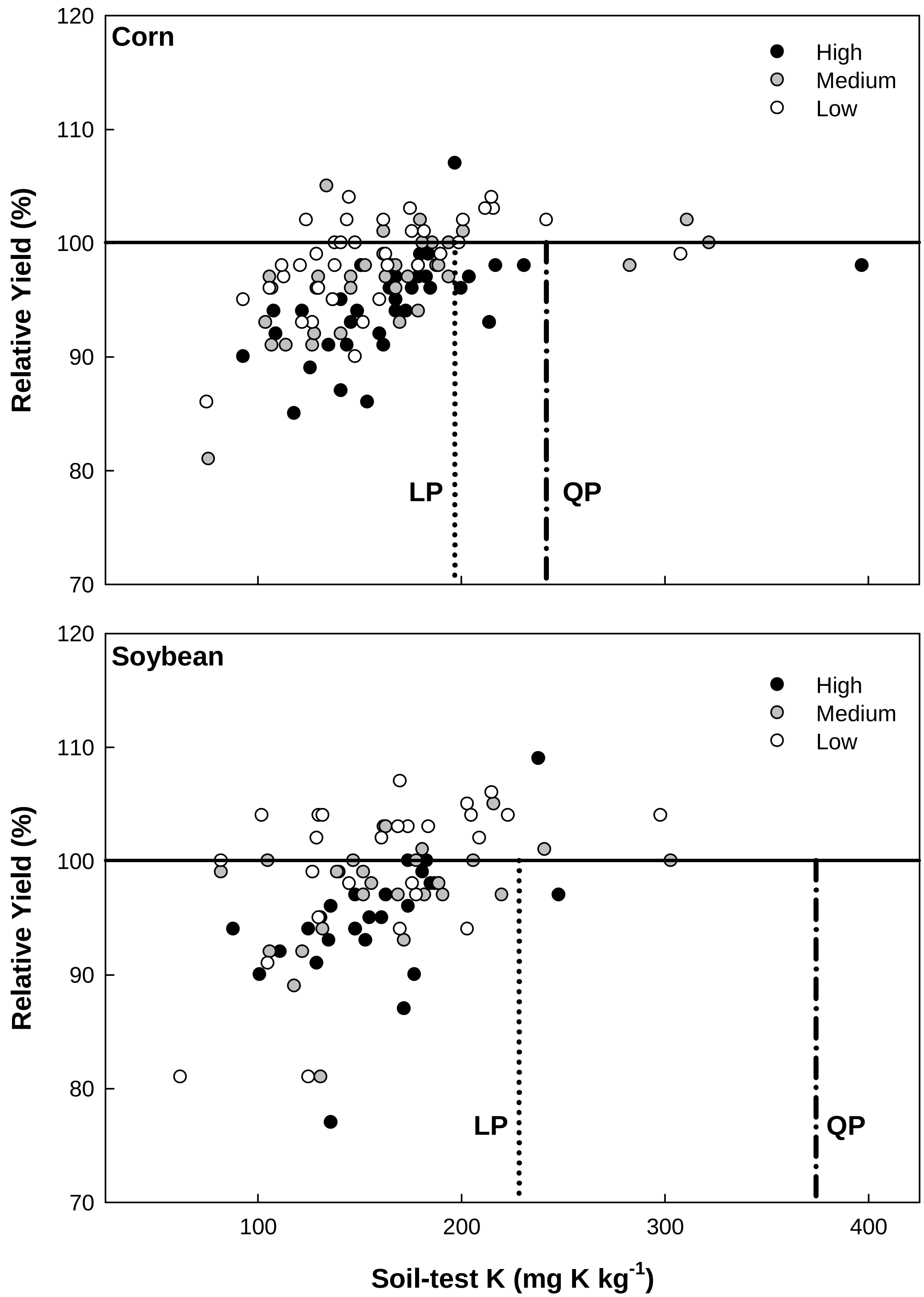

Figure 4. Relationship of relative corn and soybean grain yield with soil-test K across all sites for averages of individual cells within each yield classes (see Methods section) at each site. Vertical lines indicate critical concentrations determined by linear-plateau (LP) and quadratic-plateau (QP) models.

CHAPTER 3. DIFFERENTIAL RESPONSE OF CORN AND SOYBEAN EARLY GROWTH, POTASSIUM CONCENTRATION IN PLANT TISSUES, AND GRAIN YIELD TO POTASSIUM FERTILIZATION

A paper to be submitted to Soil Science Society of America Journal by

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ABSTRACT

Potassium is an essential nutrient for plant growth. Understanding how K fertilization affects growth and K concentration of different plant parts is needed for modern hybrids and varieties. A study based on 20, two-year field trials was conducted from 2003 to 2006 in Iowa to evaluate the effect of K fertilization on corn (*Zea mays* L.) and soybean (*Glycine max* L. Merr.) early growth; K concentration in young plants, mature leaves, and grain; and grain K removal. Five K treatments (0, 28, 56, 112, and 168 kg K ha^{-1}) were broadcast before the first crop (at ten sites for each crop) using conventional plots and four replications at each site. Potassium fertilization increased first-year crop grain yield at eight sites, and residual effects increased yield in eight sites (at only four sites were there responses in both years). All responses were observed when initial STK was Optimum or lower as currently defined in Iowa ($\leq$ 171 mg K kg^{-1}). Calculations based on response models indicated that on average across yield responsive first-year sites, rates of 91 and 103 kg K ha^{-1} maximized grain yield of corn and soybean, respectively, while the highest rate used (168 kg K ha^{-1}) maximized yield of both crops at second-year sites. Potassium fertilization

increased grain K concentration in several soybean sites regardless of the yield response, but seldom in corn. Grain K removal responses followed yield responses closely. Potassium fertilization seldom increased early crop growth but frequently increased the K concentration of young plants and mature leaves regardless of the grain yield response. The magnitude and frequency of responses to K were highest for (1) vegetative plant K concentration and uptake, (2) grain yield and K removal, (3) grain K concentration, and lowest for (4) early plant growth. The results demonstrated large luxury uptake of K by vegetative corn and soybean parts.

INTRODUCTION

Potassium is an essential nutrient needed for plant growth. Soils can provide much of the K that is needed by plants, but when supply becomes limiting, the need for supplemental K through fertilization is necessary. Research on the effects of K fertilization for corn and soybean were studied extensively in the past. For example, there were excellent publications more than 50 years ago with much information still relevant today (Nelson et al., 1945; Wittels and Seatz, 1953; Pesek, 1968). With improvements in corn hybrids and soybean varieties over the past decades, however, overall plant growth and grain yields have increased significantly and management practices also have changed. Therefore, most recent K research in the U.S. Midwest has focused more on the effects of K placement and tillage systems than on overall effects of the rate of K on the plant K uptake and grain yield. These changes have warranted an improvement in the understanding of K fertilization for today’s crops.

Potassium fertilization effects on crop grain yield have been studied for many years on small plot trials with fairly homogenous initial soil-test K (STK) levels. Previous Iowa research (Bordoli and Mallarino, 1998; Borges and Mallarino, 2000, 2001, 2003; Bermudez et al., 2001; Mallarino et al., 2004; Barbagelata et al., 2005) showed that corn and soybean responses to K fertilizer were large and likely only when STK was in the Optimum or lower interpretation categories (< 171 mg K kg^{-1}, ammonium-acetate test, 15-cm sampling depth) as defined in Iowa (Sawyer et al, 2002). Work in Minnesota showed that yield responses on a Webster soil testing 150 mg K kg^{-1} occurred in only 3 of 14 sites-years (Randall et al. 1997). Research in other regions has shown that corn responded to direct K fertilization (Vyn and Janovicek, 2001) and soybean grain yield to residual K fertilization (Yin and Vyn, 2002) when STK levels were < 100 mg K kg^{-1}. However, little work has been published recently that assessed rate of K fertilization on corn and soybean. Research done in North Carolina showed that corn and soybean yield responses to K occurred in only 1 of 3 years, with corn responding up to 112 kg K ha^{-1} (Heckman and Kamprath, 1992), and soybean responding up to 224 kg K ha^{-1} (Heckman and Kamprath, 1995). Ebelhar and Varsa (2000) showed that corn yield responded up to 168 kg K ha^{-1}, however, soybean yield decreased, on average, with rates above 56 kg K ha^{-1}. The authors concluded that soybean was more sensitive than corn to higher salt concentrations with higher rates of K. This yield decrease with relatively low K rates is surprising, and the aforementioned Iowa research has not observed soybean yield decreases with even higher K rates applied broadcast or deep banded.

Research has shown small and or inconsistent K fertilization effects on corn and soybean early growth (at the V5 to V6 stages) (Heckman and Kamprath, 1992; Heckman and Kamprath, 1995; Mallarino et al., 1999; Borges and Mallarino, 2000; Borges and Mallarino, 2003). However, it has been shown that K fertilization tends to increase the K concentrations and K uptake of vegetative tissues, often regardless of the STK level or the grain yield response (Heckman and Kamprath, 1992; Heckman and Kamprath, 1995; Randall et al., 1997; Mallarino et al., 1999; Borges and Mallarino, 2000; Ebelhar and Varsa, 2000; Yin and Vyn, 2002a, 2002b; Borges and Mallarino, 2003; Yin and Vyn, 2003). For example, Heckman and Kamprath (1992) found that corn plant K concentration at V5 to V6 always increased with increasing K rate in a 3-year study, and K uptake was increased in two years for corn regardless of the yield response. Results for soybean (Heckman and Kamprath, 1995) showed that plant K concentration increased with increasing K rate in 2 of 3 years while plant K uptake was increased in only one year. However, these authors reported that soybean leaf K concentration increased with increasing K rate in 2 of 3 years regardless of the yield response. Work in Minnesota showed that K fertilization increased corn leaf K concentration in 10 site-years of a large study, but grain yield was increased in only 3 years (Randall et al., 1997). These results agree with those by Ebelhar and Varsa (2000), who showed that regardless of the grain yield response, an increase in the K rate increased leaf K concentration of both corn and soybean in most years.

It is well known that the K concentration in soybean grain is much higher than in corn grain, and that at prevailing yield levels in the Midwest the amount of K removed is greater for soybean. However, scarce research has compared K fertilization effects on grain yield, grain K concentration, and K concentrations of vegetative tissues. Coale and Grove (1991) showed that soybean leaf K concentration, grain K concentration, uptake, and grain yield (Coale and Grove, 1990) were increased with 70 kg K ha^{-1} over the control. An unpublished Iowa study with corn at many sites (Higashi, 1991) compared K fertilization effects on several plant tissues and found that corn grain yield was increased by K fertilization at one of 28 sites and grain K concentration at five sites. However, K concentrations of young plants, ear leaves, and cornstalks at maturity were increased at most sites. Yin and Vyn (1991a) showed that K applied for a previous year crop increased soybean grain K concentration at 2 of 4 sites but no yield responses was observed at any site. Furthermore, these authors reported that the increases in leaf K concentration were much greater than for grain K concentration. Several studies (Higashi, 1991; Yin and Vyn, 2002a, 2003; Mallarino and Valadez-Ramirez, 2005) have shown that the K concentration in corn and soybean grain vary significantly across years, sites, tillage systems, and other management practices but K fertilizer and STK effects on grain K concentration are relatively smaller and inconsistent and, as a consequence, the yield level variation has the most predictable impact on K removal. This is important because STK and K removal with harvest are used to determine K fertilization rates for crops.

There is a need for more research to better understand the magnitude of fertilization effects on grain yield, K uptake, K concentration in plant parts, and K removal using modern corn hybrids and soybean varieties mainly because of renewed interest about fertilization effects on early crop growth and new interest on biomass production. Therefore, the objectives of this study were to evaluate the relative magnitude of K fertilization effects on corn and soybean grain yield and both K concentration and uptake in young plants, mature leaves in summer, and grain.

MATERIALS AND METHODS

Sites, Trials, and Treatments

Twenty two-year conventional small-plot trials with corn and soybean were established in Iowa from 2003 to 2006 (eight in 2003, four in 2004, and eight in 2005) at Iowa State University research centers located in Boone, Floyd, Hancock, O'Brien, and Washington counties. These counties are in the central, northeast, northern, northwest, and southeast regions of the state, respectively. The fields had been managed with corn-soybean rotations and encompassed wide ranges of STK. All trials were managed with chisel-plow/disk tillage following the most common practices in Iowa. Fields with corn residue were chisel plowed in the fall before snowfall and disked in spring whereas sites with soybean residue only were disked in spring. Table 1 shows information about the soils at each field. Crop management practices (except K fertilization) were those recommended for each region and, therefore, corn hybrids, soybean varieties, seeding rates, and planting dates varied among sites. Plots measured 12.2 to 18.3 m in length and either 9.1 or 12.2 m in width.

Treatments applied for the first year of all trials were five K fertilizer rates consisting of 0, 28, 56, 112, and 168 kg K ha^{-1} applied as KCl (0-0-52). The fertilizer was broadcast by hand in the fall before tillage of cornstalks and without tillage until spring for soybean residue. The treatments and four replications were arranged as a randomized complete-block design in all trials. The crops were switched to establish corn-soybean or soybean-corn sequences for the second year of the trials, and no new K fertilizer treatment was applied.

Therefore, the second year of each trial evaluated residual effects of K treatments applied before the first crop. Hereon, the code for each site-year will consist of a field number (1 through 20) followed “a” to denote the first crop or a “b” to denote the second crop, and each site-year will be referred to as a site (1a and 1b through 20a and 20b). Phosphorus fertilizer was applied for both crops as needed to buildup or maintain soil-test P in the High Iowa soil test category (21 to 30 mg P kg^{-1}, Bray-P_1 test), while a rate of 168 to 202 lb N $acre^{-1}$ was applied for corn in spring before planting (168 kg N ha^{-1} is the highest N rate recommend for corn after soybean in Iowa).

Soil and Plant Measurements

Soil samples were collected from each plot before K fertilizer application and again following crop harvest before soils froze (in late October or early November). Each sample was a composite of 12 cores collected from a 0-15-cm depth. Soil samples were analyzed for extractable K, Ca, and Mg by the ammonium-acetate test on samples dried at 35 to 40 °C (Warncke and Brown, 1998), and initial samples taken before applying treatments for the first time also were analyzed for pH, soil-test P, and organic matter. Soil pH was measured potentiometrically using a 1:1 soil:water ratio and organic matter was determined with the combustion method described by Wang and Anderson (1998). We used Iowa State University soil-test interpretations for STK (Sawyer et al., 2002). The five STK classes for soil series with low subsoil K (most in the state and in this study) are Very Low $\leq$ 90 mg K kg^{-1}; Low 91 to 130 mg K kg^{-1}; Optimum 131 to 170 mg K kg^{-1}; High 171 to 200 mg K kg^{-1}; and Very High $\geq$ 201 mg K kg^{-1}. For soil series with high subsoil K (in our study only the

Mahaska series at two fields), the boundaries for those classes are 70, 110, 150, and 180 mg K kg^{-1}.

The aboveground portion of 10 plants was sampled by cutting plants at ground level at the V5 to V6 growth stage (Fehr et al., 1971; Ritchie et al., 1986) to assess early growth (dry weight), total K concentration, and total K uptake per plant. Mature leaves were sampled and analyzed for total K concentration by collecting the blade portion of corn leaves opposite and below the ear from 10 plants at the 60 to 80% silking stage and the three top, fully mature triofoliolate leaves of 10 soybean plants at the R2 growth stage (Fehr et al., 1971). Grain was harvested from a central area of each plot (12.2 to 18.3 m length of three to five rows) with a plot combine in most sites except in Boone County, where a 7.6-m section of two central rows was hand-harvested from each plot and ears were threshed using a stationary sheller. A subsample of grain was collected for analysis of grain K concentration. Grain yields were adjusted to 130 and 155 g kg^{-1} moisture for soybean and corn, respectively. All plant samples (plant early growth, leaf, and grain) were dried at $60^{o}C$ in a forced-air oven, weighed (except the mature leaves) and ground to pass through a 2-mm screen. Total K was measured by digesting 0.25 g of material with sulfuric acid and hydrogen peroxide (Digesdahl Analysis System, Hach, Boulder, CO) and measuring the K in the digests by emission. Total plant K uptake was calculated from the early growth plant K concentration and dry weights, and grain K removal was calculated from the grain K concentration and yield.

Evaluation of Responses to Fertilization

An ANOVA was conducted on all measurements for each corn and soybean site to determine whether or not there was a response ($P \leq 0.10$) to K assuming a RCBD using PROC MIXED of SAS (SAS Institute, 2000), in which fertilization was considered a fixed effect and replication (blocks) was considered a random effect. The treatment sum of squares were partitioned into an orthogonal comparison of the control (0 kg K ha^{-1}) vs. the mean of the four fertilizer rate treatments and single degree of freedom contrasts to test for linear and curvilinear (quadratic) responsive trends. Sites were classified as responsive based on a significant response ($P \leq 0.10$) as indicated by the main effect of treatments, the comparison of the control vs. fertilized treatments, or the linear trend to study crop responses across responsive sites for each crop. The responses to K at each responsive site and for averages across responsive sites was further studied by fitting linear, quadratic, linear-plateau (LP), and quadratic-plateau (QP) response models using the GLM (for linear and quadratic) or NLIN (for LP and QP) procedures of SAS (Cerrato and Blackmer, 1990; SAS Institute, 2000). We chose quadratic, LP or QP models to describe a crop response only when the residual sums of squares were significantly smaller ($P \leq 0.10$) than for the linear model. When the three complex models were significantly better than the linear model, we chose the one with highest adjusted R^2 (SAS Institute, 2000), but did not choose the quadratic model when it predicted a decrease after a maximum within the range of K rates used that was not clear from the observed data because this is a well known problem for this model (Cerrato and Blackmer, 1990).

RESULTS AND DISCUSSION

Grain Yield Responses

Potassium fertilization increased ($P \leq 0.10$) corn grain yield in the first year at four sites (Sites 6a, 13a, 14a, and 15a) and soybean grain yield at four sites (Sites 2a, 5a, 12a, and 18a) (Table 2). Comparisons of yield responses and STK levels prior to K fertilization indicate that the results for the responsive sites in general were reasonable because mean STK levels at each site ranged from 130 to 173 mg K kg^{-1} (Table 1). Seven of the sites tested Optimum according to Iowa STK interpretation (Sawyer et al., 2002), and one site tested borderline between the Optimum and High classes (Site 13a). Fertilization based on crop K removal to maintain STK is recommended for the Optimum category. However, there was no yield response at the two low testing sites (Sites 19a and 20a), seven other sites that tested Optimum, or at the three sites that tested High or Very High. Previous research indicated that the probability of a yield response within each of these categories is 60%, 25%, 5% and < 1% for the Low, Optimum, High, and Very High classes (Sawyer et al., 2002). Potassium fertilization seemed to have resulted in a yield decrease at Sites 3a (corn) and 19a (soybean). The response at each of these sites was small and unexpected given K rates applied and the broadcast application method used. We believe that these negative responses were probably due to experimental error or random effects.

Residual K fertilization from the first year applications increased ($P \leq 0.10$) second-year corn grain yield at five sites (Sites 5b, 10b, 11b, 18b, and 19b) and soybean grain yield at three sites (Sites 6b, 14b, and 20b) (Table 2). The STK levels of the control plots before the second crop year sites ranged from 103 to 156 mg K kg^{-1} for the RC sites and 119 to 150 mg K kg^{-1} for the RS sites (Table 8). Four of the sites tested Low (Sites 5b, and 19b for corn and 6b and 20b for soybean) and four tested Optimum (Sites 10b, 11b, and 18b for corn and 15b for soybean). Comparisons of yield responses for the first- and second-year sites showed that crops at eight sites (Sites 5a, 5b, 6a, 6b, 14a, 14b, 18a, and 18b) responded in both the first and second years. As expected, the STK of the control plots between the first and second crops was lower than the first year's whole plot average. The decreases in STK ranged from 3 mg K kg^{-1} (site 18b) to 28 mg K kg^{-1} (site 5b). Only at one site (Site 11b) was there a second-year crop response with no first-year response, which is explained by a much lower STK in the control plots before the second year (62 mg K kg^{-1} less). Such a large apparent STK decrease in one year must be explained by large within-site initial STK variation.

The average corn and soybean grain yields across first-year and second-year sites with statistically significant or non-significant yield responses to K fertilization are shown in Table 3. The response across first-year corn yield responsive (RC) sites and soybean yield responsive (RS) sites followed a linear-plateau trend. Calculations based on the response models indicated that on average for these sites, corn grain yield responded linearly up to 91 kg K ha^{-1} while soybean responded linearly up to 103 kg K ha^{-1}. As expected, there was no grain yield response to K fertilization across the corn yield non-responsive (NRC) sites or soybean yield non-responsive (NRS) sites. The average second-year crops response to residual K fertilization followed a linear trend for both RC and RS sites (up to 168 kg K ha^{-1}, the highest K rate used in the study).

Grain K Concentration and Removal Responses

Potassium fertilization increased ($P \leq 0.10$) first-year corn grain K concentration only at Site 4a and soybean grain K concentration at six sites (Sites 5a, 8a, 11a, 12a, 18a, and 19a), while residual K fertilization effects increased grain K concentration of second-year crops at three corn sites (Site 5b, 12b, and 18b) and four soybean sites (Sites 6b, 9b, 14b, and 15b) (Table 4). Potassium fertilization increased grain K removal of first-year crops at one corn site (Site 6a) and soybean grain K removal at six sites (Sites 2a, 5a, 11a, 12a, 18a, 19a), while residual K fertilization effects increased grain K removal of second-year crops at two corn sites (Sites 5b and 18b) and five soybean sites (Sites 6b, 9b, 14b, 15b, and 20b) (Table 5). Corn grain yield response appeared to have little relation to grain K concentration and grain K removal with harvest. For first-year corn, a grain K removal response was found only at Site 6a, which did have a yield response, and a first-year grain K concentration response was only found at Site 4a, which did not have a yield response. For second-year corn, both grain K concentration and K removal responses were observed at Sites 5b and 19b, which were two of the five yield responsive sites, and a grain K concentration response was found at Site 12b where there was no yield response. However, these measurements showed a better relationship for soybean. There was a soybean grain K removal response in all first-year sites with a yield response (Sites 2a, 5a, 12a, and 18a) and a grain K concentration response at three of the four sites with a yield response (Sites 5a, 12a, and 18a). Soybean grain K concentration and K removal responses to K fertilization were also found at first-year Sites 11a and 19a, where there was no yield response, and a grain K concentration response also was found at Site 8a, where neither yield nor grain K removal was responsive. For second-year soybean sites, there was grain K removal response at all yield responsive sites and there was grain K concentration response at two of the three yield responsive sites (Sites 6b and 14b). Also, grain K concentration and K removal responses to K fertilization were also found at Sites 9b and 15b, where there was no soybean yield response.

The average grain K removal across first-year grain yield responsive sites followed a curvilinear trend for RC sites up to 138 kg K ha^{-1} and a linear trend for RS sites up to 110 kg K ha^{-1}, while for second-year crops the responsive trends were linear for both RC and RS sites (up to 168 kg K ha^{-1}, the highest K rate used in the study) (Table 6). There was no average grain K removal response to K fertilization at either the corn yield non-responsive (NRC) sites or soybean yield non-responsive (NRS) sites. Comparing response models for grain yield and grain K removal shows that trends in K removal followed grain yield closely. One average, soybean grain K removal was 23 and 33 kg K ha^{-1} more than for corn in the first- and second-year sites, respectively.

In contrast to grain yield and grain K removal responses, direct or residual K fertilization on average had no effect ($P \leq 0.10$) on corn grain K concentration regardless of the grain yield response (Table 7). In soybean, however, there was a grain K concentration response for both yield responsive and not responsive sites. Average soybean grain K concentration across yield responsive first-year sites responded linearly up to 116 kg K ha^{-1}, while the response was up to 168 kg K ha^{-1} in sites with no grain yield response. For second-year crops, there was an average grain K concentration response up to 65 kg K ha^{-1} for yield responsive sites and a linear trend up to 168 kg K ha^{-1} for sites with no grain yield response.

Summary of Grain Responses

Results of corn and soybean grain yield responses to direct or residual K fertilization showed that K increased yield only when STK levels were within interpretation categories where a response to K is likely (Optimum or lower, i.e. < 171 mg K kg^{-1}). These results agree with results at most sites included in published work done in Iowa since the soil test method for K was changed from field-moist to dried samples (Bordoli and Mallarino, 1998; Borges and Mallarino, 2000, 2001, 2003; Bermudez et al., 2001; Mallarino et al., 2004; Barbagelata et al., 2005; Sawchik and Mallarino, 2007). The previous studies reported that corn and soybean managed with chisel-plow tillage, no-tillage, or ridge-tillage responded to K fertilizer in about 5% of the sites testing higher than 170 mg K kg^{-1}. Work in Minnesota showed that yield responses on a Webster soil testing 150 mg K kg^{-1} occurred in only 3 of 14 sites-years (Randall et al. 1997). Research in other regions has shown that corn grain yield responded to direct K fertilization (Vyn and Janovicek, 2001) and soybean grain yield to residual K fertilization (Yin and Vyn, 2002) when STK levels were < 100 mg K kg^{-1}. Comparisons of corn grain yield, K concentration, and K removal responses showed responses for the three measurements were inconsistent across the corn sites. Results for soybean showed, however, that grain K concentration and K removal responses were observed at most grain yield responsive sites, and at some yield non-responsive sites.

Comparisons of the K rate that produced the maximum for corn grain yield and grain K removal (as predicted by the models) across yield responsive first-year sites showed that the rate was 47 kg K ha^{-1} higher for grain K removal than for grain (Tables 3 and 6). Comparisons of the K rate that resulted in maximum soybean grain yield, grain K removal, and grain K concentration across yield responsive first-year sites showed little difference, however, and rates of 103, 110, and 116 kg K ha^{-1}, respectively, maximized those measurements. Across second-year yield responsive sites, 168 kg K ha^{-1}, the highest K rate used in the study, maximized both corn and soybean grain yield and grain K removal, however, while 65 kg K ha^{-1} maximized soybean grain K concentration. We expected that higher K rates would maximize all measurements in both second-year crops because these crops evaluated residual effects of rates applied before the previous crops. Therefore, reasons for a lower K rate requirement to maximize soybean K concentration in the second year are unclear.

Corn and Soybean Early Growth Response

Results for first-year crops (Table 9) showed that K fertilization increased ($P \leq 0.1$) corn early growth (plant DW at V5 to V6 stage) at three sites (Sites 6a, 15a, and 20a) and soybean early growth at two sites (Sites 12a and 18a). Results from the second-year crops showed that significant increases in early growth occurred only in corn at Sites 5b and 18b. Comparisons of corn grain yield and early growth responses to K showed that K fertilization increased both measurements in two of the three first-year sites with growth response (Sites 6a and 15a) and in both second-year sites with growth response. However, there were five corn sites (across first and second years) with a grain yield response to K but no early growth response. Soybean grain yield responses occurred in both sites where K increased early growth the first year. However, there were five sites (across first- and second-year soybean) with a grain yield response to K but no early growth response.

Study of averages across all first-year sites where an early plant growth response was observed (not shown) indicated that corn growth responded up to 56 kg K ha^{-1} and soybean growth responded up to 28 kg K ha^{-1}. Similar study for second-year sites indicated that only corn growth responded up to 28 kg K ha^{-1}. When the plant growth responses were averaged across grain yield responsive and non-responsive sites separately, the only observed early growth response was up to the 28 kg K ha^{-1} rate in the yield responsive second-year corn sites (Table 10). The results for plant early growth at each site and averages across sites with or without a grain yield response demonstrate an interesting point. In sites where an early plant growth response to K fertilization was observed, a subsequent response in grain yield was likely. However, there were grain yield responses to K at many sites where an early growth response was not observed. Therefore, our results demonstrate that grain yield responses are not necessarily dependant on early growth responses for either corn or soybean. These results agree with previous studies in showing that early growth response to K fertilization is not a good predictor of grain yield response (Mallarino et al. 1999; Borges and Mallarino, 2001; Borges and Mallarino, 2003).

Corn and Soybean Early Plant Potassium Concentration and Uptake

Potassium fertilization increased ($P \leq 0.1$) the K concentration of young corn plants at eight first-year sites and of soybean plants at nine first-year sites (Table 11). Fertilization did not increase plant K concentrations at corn Sites 3a and 4a nor at soybean Site 16a. Results from second-year sites showed that residual K fertilization increased the plant K concentration of young corn plants at all sites, and soybean K concentration at seven sites. Fertilization did not increase soybean plant K concentrations at Sites 3b, 4b, and 7b. Results for plant K uptake were similar to plant K concentration (Table 13). Results for first-year sites showed that K fertilization increased K uptake at eight corn sites and seven soybean sites. Fertilization did not increased plant K uptake in corn at Sites 4a and 7a, nor in soybean at Sites 1a, 10a, and 16a. Results from second-year sites showed that K fertilization increased K uptake in all corn sites, and soybean K uptake at six sites. Fertilization did not increase plant K uptake in soybean at Sites 3b, 4b, 7b, and 9b.

Comparisons of yield, early growth, plant K concentration, and uptake responses to K by first-year crops and residual responses by second-year crops showed that plant K concentration and uptake responses to K fertilization were much more frequent than both grain yield and early growth responses. However, regardless of the crop and direct or residual response evaluations, no grain yield or early growth responses to K fertilization were found when there was no response in plant K concentration or K uptake.

When averaged across all first-year corn and soybean with or without a grain yield-response, the plant K concentration response across the RC, RS, and NRS sites followed a linear-plateau trend, while NRC sites followed a linear trend (Table 12). Calculations based on the response models indicated that on average for these sites, plant K concentrations for the RC sites responded linearly up to 124 kg K ha^{-1}, RS sites responded up to 92 kg K ha^{-1}, NRC sites responded up to 168 kg K ha^{-1}, and NRS sites up to 80 kg K ha^{-1}. The average plant K uptake for the first-year sites followed a curvilinear trend for RC and RS sites up to 142 and 110 kg K ha^{-1}, respectively, and a linear trend up to 168 kg K ha^{-1} for both NRC and NRS sites (Table 14). Results from second year sites showed that residual effects of K fertilization for the first-year crops increased K concentration in young plants at all sites with a grain yield response (RC, RS, NRC, and NRS) up to the highest rate applied in the study of 168 kg K ha^{-1} (Table 12). On average early plant K uptake by the second-year crops (Table

14) responded significantly to residual effects of K fertilization for the first-year crops, and the highest K rate used in the study (168 kg K ha^{-1}) maximized uptake.

The results show that in site-years where no responses in K concentration or K uptake were found, no grain yield or early growth responses were found either. However, there were many sites where a K concentration or K uptake response was found that did not show significant early growth or grain yield responses. These results further demonstrate that frequent and large plant K concentration and K uptake responses to K fertilization do not necessarily result in increased grain yield. Previous studies done in Iowa showed that luxury uptake of K in corn and soybean young plants (larger increases or response to higher K rates than for plant DW) are very poor predictors of grain yield responses (Borges and Mallarino, 2001; Borges and Mallarino, 2003; Mallarino et al. 1999). Luxury uptake occurs when fertilization increases the concentration of a nutrient in a tissue without increasing dry matter yield (Macy, 1936; Steenbjerg, 1951).

Corn and Soybean Leaf Potassium Concentrations

Potassium fertilization increased ($P \leq 0.1$) the leaf K concentration at all 20 first-year corn and soybean sites, in all 10 second-year corn sites, and 9 of 10 second-year soybean sites (Table 15). Fertilization did not increase soybean leaf K concentration at Site 7b, which was consistent with no response for any other measurement although reasons are not clear. When leaf K concentration data from individual first- and second-year sites were averaged across corn or soybean grain yield responsive sites (Table 16), the average response trends for both responsive and non-responsive sites followed a curvilinear trend. However, calculations based on the response models indicated that on average, leaf K concentration responded up to 168 kg K ha^{-1}, the highest rate applied in the study, regardless of grain yield response. Other research has shown that K fertilization increases corn and soybean leaf K concentration frequently and often regardless of a grain yield response (Randall et al. 1997; Vyn and Janovicek, 2001; Yin and Vyn, 2003).

The results for leaf K concentration response to K fertilization in general were similar for plant K concentration and plant K uptake in that responses were larger or to a higher K fertilizer rate than for grain measurements and that large plant tissue K concentration or uptake responses not always resulted in grain yield or grain K removal increases.

SUMMARY AND CONCLUSIONS

Potassium fertilization and residual K fertilization increased corn and soybean grain yield at 16 sites when initial STK was Optimum or lower as currently defined in Iowa (≤ 171 mg K kg^{-1}). When averaged across yield responsive first-year sites, the corn grain yield responded up to 91 kg K ha^{-1} and soybean responded up to 103 kg K ha^{-1}. Effects of residual K fertilization at second-year sites showed that both crops responded up to 168 kg K ha^{-1}. Potassium fertilization seldom increased corn grain concentration and did not increase it on average across yield responsive sites. In soybean, however, fertilization increased grain K concentration in several yield responsive and not responsive sites. On average, soybean grain K concentration across yield responsive first-year and residual sites responded up to 116 and 65 kg K ha^{-1}, respectively, while in sites with no yield response a rate of 168 kg K ha^{-1} maximized K concentration in both first-year and residual sites. Grain K removal responses followed more closely yield responses than K concentration responses. On average across yield responsive sites, 138 and 168 kg K ha^{-1} maximized corn K removal in first-year and residual sites, respectively, while 110 and 168 kg K ha^{-1} maximized soybean K removal in first-year and residual sites, respectively. On average across sites with no yield response, there was no average grain K removal response for corn or soybean, however.

Results showed that early plant growth responses to K fertilization were infrequent, and that the responsive sites for early growth and grain yield seldom coincided. Potassium fertilization frequently increased plant K concentration, plant K uptake, and leaf K concentration in both first- and second-year sites, often regardless of a yield response within that year. However, results showed that when there were no early plant K concentration, early plant K uptake, or leaf K concentration responses to K fertilization,n there were no grain yield responses either. The K fertilizer rates that maximized plant K concentration, plant K uptake, and leaf K concentration for first-year or residual sites of both crops ranged from 92 to 168 kg K ha^{-1} on average across sites that showed a grain yield response. However, the highest K rate used in the study (168 kg K ha^{-1}) maximized these three plant and leaf measurements for corn, and K uptake and leaf K concentration for soybean in sites that showed no direct or residual grain yield response to K.

Overall, results showed large differences in the relative magnitude of the response to K fertilization by different corn and soybean plant parts. With few differences between crops, the study identified four groups of plant parts each with contrastingly different responses to K fertilizer. In order of higher to lower magnitude of response, frequency of response, and K rate to reach a maximum these were (1) vegetative plant tissue K concentration and uptake, (2) grain yield and grain K removal, (3) grain K concentration, and (4) early plant growth. One significant difference between crops was that K fertilization did not affect grain K concentration of corn but sometimes increased grain K concentration of soybean. These results clearly showed luxury uptake of K by the vegetative plant parts because frequent and large K concentration and uptake responses seldom resulted in grain yield and grain K removal responses.

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Table 1. Location, year, soil series, and soil-test information in the experimental areas from soil samples collected before treatment application the first time.

Site	County	Year	Series	Soil Type Classification	Soil-test values K	Ca	Mg	pH	OM
					----------------------mg K kg^{-1}------------------				g kg^{-1}
1	Boone	2005	Canisteo	Typic Endoaquolls	163	-	-	-	-
2	Boone	2005	Canisteo	Typic Endoaquolls	139	-	-	-	-
3	Boone	2005	Nicollet	Aquic Hapludolls	150	-	-	-	-
4	Boone	2005	Nicollet	Aquic Hapludolls	234	-	-	-	-
5	Boone	2003	Webster	Typic Endoaquolls	153	5190	355	7.3	67
6	Boone	2003	Webster	Typic Endoaquolls	133	3523	442	6.6	47
7	Floyd	2004	Clyde	Typic Endoaquolls	196	4743	634	6.7	84
8	Floyd	2004	Kenyon	Typic Hapludolls	170	4547	638	6.7	75
9	Hancock	2004	Nicollet	Aquic Hapludolls	162	3685	621	5.7	54
10	Hancock	2004	Canisteo	Typic Endoaquolls	138	4708	609	6.7	47
11	O'Brien	2005	Primghar	Aquic Hapludolls	213	-	-	-	-
12	O'Brien	2003	Primghar	Aquic Hapludolls	154	3754	662	6.2	52
13	O'Brien	2003	Galva	Typic Hapludolls	173	4010	717	6.3	53
14	O'Brien	2005	Galva	Typic Hapludolls	170	-	-	-	-
15	Washington	2003	Mahaska	Aquertic Argiudolls	141	2790	585	6.4	44
16	Washington	2005	Nira	Aquertic Argiudolls	148	-	-	-	-
17	Washington	2005	Taintor	Vertic Argiaquolls	134	-	-	-	-
18	Washington	2003	Mahaska	Aquertic Argiudolls	130	2720	584	6.3	44
19	Boone	2003	Clarion	Typic Hapludolls	102	2674	359	6.7	35
20	Boone	2003	Clarion	Typic Hapludolls	117	2878	356	6.7	40

Table 2. Mean corn and soybean grain yield response to K fertilization for each K treatment applied the first year of 2-year trials.

		Treatment (kg K ha^{-1})						
Site†	Crop	0	28	56	112	168	Statistics	
		Mg ha^{-1}						
1a	Soybean	3.72	3.51	3.52	3.53	3.60	NS	
2a	Soybean	3.60	3.66	3.84	3.93	3.78	**	‡
3a	Corn	12.08	12.92	11.79	12.12	11.67	**	§
4a	Corn	12.74	12.79	13.07	12.46	12.45	NS	
5a	Soybean	2.31	2.26	2.32	2.68	2.54	**	§
6a	Corn	8.01	8.35	8.68	9.35	9.31	*	§
7a	Corn	12.75	12.92	12.89	13.05	13.11	NS	
8a	Soybean	4.30	4.26	4.27	4.19	4.14	NS	
9a	Corn	12.69	12.69	12.30	12.20	12.91	NS	
10a	Soybean	3.35	3.35	3.24	3.49	3.35	NS	
11a	Soybean	3.72	3.75	3.83	3.80	3.84	NS	
12a	Soybean	3.02	3.06	3.18	3.24	3.18	*	§
13a	Corn	10.37	11.35	11.03	11.36	10.74	**	‡
14a	Corn	11.33	11.55	11.66	11.78	11.76	*	§
15a	Corn	11.90	11.65	12.16	12.69	12.69	**	§
16a	Soybean	4.80	4.37	4.66	4.51	4.57	NS	
17a	Corn	10.41	10.38	9.66	10.08	10.11	NS	
18a	Soybean	3.08	3.19	3.30	3.42	3.46	***	§
19a	Soybean	2.10	1.87	2.03	2.27	1.91	**	¶
20a	Corn	10.34	10.33	10.79	10.42	10.51	NS	
1b	Corn	12.23	12.09	11.94	11.59	11.61	NS	
2b	Corn	11.51	11.50	11.27	12.07	11.38	NS	
3b	Soybean	2.76	2.78	2.80	2.78	2.86	NS	
4b	Soybean	2.89	2.83	2.89	2.89	2.87	NS	
5b	Corn	10.78	11.33	10.65	13.55	13.52	***	§
6b	Soybean	2.86	2.91	3.26	3.33	3.37	***	§
7b	Soybean	4.40	4.33	4.33	4.36	4.21	NS	
8b	Corn	13.43	13.49	13.32	13.69	13.61	NS	
9b	Soybean	4.12	4.09	4.05	4.17	4.15	NS	
10b	Corn	11.58	12.03	11.78	11.68	12.20	**	§
11b	Corn	9.36	9.39	9.78	9.82	9.98	**	§
12b	Corn	5.00	4.92	4.99	5.15	5.38	NS	
13b	Soybean	2.43	2.47	2.38	2.39	2.41	NS	
14b	Soybean	3.57	3.50	3.75	3.80	3.87	**	§
15b	Soybean	3.93	4.12	4.11	4.14	4.09	NS	
16b	Corn	11.94	11.89	11.98	12.22	12.33	NS	
17b	Soybean	4.27	4.28	4.20	4.29	3.74	NS	
18b	Corn	11.47	12.48	12.04	12.10	13.27	***	§
19b	Corn	11.29	12.29	11.74	11.49	12.03	***	§
20b	Soybean	2.89	2.77	3.09	3.13	3.24	**	§

* Significant at the 0.10 probability level.
** Significant at the 0.05 probability level.
*** Significant at the 0.01 probability level.
NS, nonsignificant at the 0.10 probability level.

† Suffixes "a" and "b" in the site code identify the first and second crop at a given location.
‡ Quadratic response
§ Linear response
¶ Significant difference between control and K treatments.

Table 3. Corn and soybean grain yield response to K fertilization when averaged across first and second-year grain yield responsive and non-responsive sites.

			Treatment (kg K ha^{-1})						
Response	Crop	Year†	0	28	56	112	168	Statistics	YMR‡
			Mg ha^{-1}						kg K ha^{-1}
Responsive	Corn	a	10.40	10.72	10.88	11.29	11.13	** §	91
Responsive	Soybean	a	3.00	3.04	3.16	3.32	3.24	* §	103
Non-Responsive	Corn	a	11.83	12.01	11.75	11.72	11.79	NS	-
Non-Responsive	Soybean	a	3.67	3.52	3.59	3.63	3.57	NS	-
Responsive	Corn	b	10.90	11.51	11.20	11.73	12.20	** ¶	168
Responsive	Soybean	b	3.11	3.06	3.37	3.42	3.49	** ¶	168
Non-Responsive	Corn	b	10.82	10.78	10.70	10.94	10.86	NS	-
Non-Responsive	Soybean	b	3.54	3.56	3.54	3.57	3.48	NS	-

* Significant at the 0.10 probability level.

** Significant at the 0.05 probability level.

*** Significant at the 0.01 probability level.

NS, nonsignificant at the 0.10 probability level.

† "a" and "b" in the year identify the first and second crop at a given location.

‡ YMR, yield maximizing rate of fertilizer as determined by the model.

§ Linear-plateau response.

¶ Linear response (the highest K rate used by the study for linear models).

Table 4. Mean corn and soybean grain K concentration response to K fertilization for each K treatment applied the first year of 2-year trials.

		Treatment (kg K ha^{-1})						
Site†	Crop	0	28	56	112	168	Statistics	
		g K kg^{-1}						
1a	Soybean	20.5	21.1	20.6	20.7	21.3	NS	
2a	Soybean	18.8	18.8	19.2	19.5	19.4	NS	
3a	Corn	3.5	3.7	3.4	3.6	3.5	NS	
4a	Corn	3.3	3.4	3.4	3.6	3.7	***	‡
5a	Soybean	14.1	15.0	16.1	17.4	17.6	***	‡
6a	Corn	3.8	3.8	3.8	3.7	4.2	NS	
7a	Corn	1.6	1.6	1.6	1.7	1.6	NS	
8a	Soybean	17.8	17.7	18.1	18.0	18.4	*	‡
9a	Corn	2.1	2.2	2.1	2.2	2.2	NS	
10a	Soybean	18.8	18.5	18.6	19.0	19.4	NS	
11a	Soybean	18.3	18.8	19.5	19.0	19.0	**	§
12a	Soybean	18.2	18.2	18.1	19.2	19.7	**	‡
13a	Corn	3.9	3.6	3.9	3.9	3.9	NS	
14a	Corn	3.0	3.3	3.0	3.3	3.1	NS	
15a	Corn	2.6	2.7	2.8	2.6	2.6	NS	
16a	Soybean	18.7	18.7	19.1	18.7	19.7	NS	
17a	Corn	2.9	3.0	3.1	3.0	3.0	NS	
18a	Soybean	16.3	16.4	17.1	18.1	17.6	**	‡
19a	Soybean	17.4	19.0	19.0	19.7	20.3	***	‡
20a	Corn	3.6	3.7	3.7	3.7	3.8	NS	
1b	Corn	4.0	4.0	4.0	4.0	4.0	NS	
2b	Corn	4.0	4.4	4.0	4.0	4.2	NS	
3b	Soybean	23.5	23.7	22.6	23.0	24.3	NS	
4b	Soybean	21.5	21.2	22.0	21.2	21.9	NS	
5b	Corn	1.6	1.6	1.5	1.8	1.8	*	‡
6b	Soybean	16.6	17.1	17.4	17.0	17.8	**	§
7b	Soybean	19.6	20.1	20.4	20.2	19.6	NS	
8b	Corn	3.0	3.0	2.8	3.0	3.0	NS	
9b	Soybean	20.7	21.5	21.9	22.5	21.9	**	§
10b	Corn	4.3	3.9	4.1	4.1	4.0	*	‡
11b	Corn	3.9	3.9	3.8	3.8	4.0	NS	
12b	Corn	1.6	2.0	1.8	1.8	2.0	**	§
13b	Soybean	18.0	18.0	17.8	17.5	18.1	NS	
14b	Soybean	20.0	20.0	20.6	21.2	20.7	*	‡
15b	Soybean	15.8	15.6	16.0	16.8	16.8	***	‡
16b	Corn	4.1	3.9	4.1	4.2	4.1	NS	
17b	Soybean	20.2	19.6	20.0	20.8	20.8	NS	
18b	Corn	1.3	1.5	1.5	1.8	1.7	*	§
19b	Corn	1.5	1.3	1.5	1.4	1.6	NS	
20b	Soybean	16.8	16.6	17.3	16.9	17.4	NS	

* Significant at the 0.10 probability level.
** Significant at the 0.05 probability level.
*** Significant at the 0.01 probability level.
NS, nonsignificant at the 0.10 probability level.
† Suffixes "a" and "b" in the site code identify the first and second crop at a given location.
‡ Linear response.
§ Significant difference between control and K treatments.

Table 5. Mean corn and soybean grain K removal response to K fertilization for each K treatment applied the first year of 2-year trials.

		Treatment (kg K ha^{-1})						
Site†	Crop	0	28	56	112	168	Statistics	
		------------------	------------------	kg K ha^{-1}	------------------	------------------		
1a	Soybean	76.1	74.3	72.3	72.9	76.9	NS	
2a	Soybean	67.7	68.7	73.8	76.6	73.3	*	‡
3a	Corn	42.3	47.2	40.4	43.6	40.6	NS	
4a	Corn	42.3	43.8	44.8	44.5	46.1	NS	
5a	Soybean	32.7	36.9	37.2	46.6	44.7	***	‡
6a	Corn	30.0	32.0	32.9	34.9	38.8	**	‡
7a	Corn	21.0	19.2	20.3	21.7	19.5	NS	
8a	Soybean	76.4	75.4	77.1	75.5	76.4	NS	
9a	Corn	26.4	28.4	25.3	27.1	27.9	NS	
10a	Soybean	63.1	61.9	60.4	66.4	64.8	NS	
11a	Soybean	68.1	70.5	74.4	71.9	72.9	*	§
12a	Soybean	54.9	55.5	57.6	60.8	62.6	**	‡
13a	Corn	41.6	41.2	43.2	44.2	41.6	NS	
14a	Corn	33.7	37.9	34.7	38.6	36.2	NS	
15a	Corn	30.7	31.2	33.7	32.7	33.0	NS	
16a	Soybean	89.8	81.7	89.1	83.8	90.4	NS	
17a	Corn	30.7	31.2	30.0	30.5	30.0	NS	
18a	Soybean	50.1	52.5	56.4	61.8	60.7	***	‡
19a	Soybean	36.6	35.4	38.5	44.5	38.7	***	‡
20a	Corn	37.5	38.0	39.6	37.0	39.6	NS	
1b	Corn	47.7	48.4	48.1	45.9	46.5	NS	
2b	Corn	44.8	49.8	44.7	48.6	48.2	NS	
3b	Soybean	64.9	63.1	63.3	63.7	69.2	NS	
4b	Soybean	62.1	59.8	63.6	61.4	62.7	NS	
5b	Corn	16.6	18.4	15.7	24.3	24.6	***	‡
6b	Soybean	47.5	49.7	56.7	56.5	59.9	***	‡
7b	Soybean	86.2	87.1	88.2	87.8	82.6	NS	
8b	Corn	39.9	40.0	37.6	41.1	41.5	NS	
9b	Soybean	85.3	88.1	88.7	93.7	90.7	*	§
10b	Corn	50.2	46.3	48.3	47.6	45.9	NS	
11b	Corn	35.7	36.2	37.4	36.8	39.4	NS	
12b	Corn	7.4	10.1	9.0	9.1	10.1	NS	
13b	Soybean	43.9	44.4	42.5	41.6	43.5	NS	
14b	Soybean	71.2	70.2	77.2	80.7	80.0	***	‡
15b	Soybean	62.3	64.5	65.7	69.4	68.8	**	§
16b	Corn	48.4	46.1	49.2	50.9	49.9	NS	
17b	Soybean	86.2	79.6	83.6	89.0	77.6	NS	
18b	Corn	14.8	18.1	19.4	22.0	22.5	**	§
19b	Corn	15.9	15.6	17.0	15.7	19.0	NS	
20b	Soybean	48.5	46.1	53.7	52.8	56.4	*	‡

* Significant at the 0.10 probability level.
** Significant at the 0.05 probability level.
*** Significant at the 0.01 probability level.
NS, nonsignificant at the 0.10 probability level.
† Suffixes "a" and "b" in the site code identify the first and second crop at a given location.
‡ Linear response.
§ Significant difference between control and K treatments.

Table 6. Corn and soybean grain K removal response to K fertilization when averaged across first and second-year grain yield responsive and non-responsive sites.

			Treatment (kg K ha^{-1})							
Response	Crop	Year†	0	28	56	112	168	Statistics		YMR‡
			------------------------------kg K ha^{-1}---------------------------							kg K ha^{-1}
Responsive	Corn	a	34.0	35.5	36.1	37.6	37.4	***	§	138
Responsive	Soybean	a	51.3	53.4	56.3	61.5	60.3	***	¶	110
Non-Responsive	Corn	a	33.4	34.6	33.4	34.1	33.9	NS		-
Non-Responsive	Soybean	a	68.3	66.6	68.6	69.2	70.0	NS		-
Responsive	Corn	b	26.6	26.9	27.6	29.3	30.3	***	††	168
Responsive	Soybean	b	55.7	55.3	62.5	63.4	65.4	**	††	168
Non-Responsive	Corn	b	37.7	38.9	37.7	39.1	39.2			-
Non-Responsive	Soybean	b	70.1	69.5	70.8	72.4	70.7			-

* Significant at the 0.10 probability level.

** Significant at the 0.05 probability level.

*** Significant at the 0.01 probability level.

NS, nonsignificant at the 0.10 probability level.

† "a" and "b" in the year identify the first and second crop at a given location.

‡ YMR, yield maximizing rate of K fertilizer as determined by the model.

§ Quadratic-plateau response.

¶ Linear-plateau response.

†† Linear response (the highest K rate used by the study for linear models).

Table 7. Corn and soybean grain K concentration response to K fertilization when averaged across first and second-year grain yield responsive and non-responsive sites.

			Treatment (kg K ha^{-1})						
Response	Crop	Year†	0	28	56	112	168	Statistics	YMR‡
			------------------------------g K kg^{-1}				----------------------------		kg K ha^{-1}
Responsive	Corn	a	3.3	3.3	3.4	3.4	3.4	NS	-
Responsive	Soybean	a	16.8	17.1	17.6	18.5	18.6	*** §	116
Non-Responsive	Corn	a	2.9	2.9	2.9	3.0	2.9	NS	-
Non-Responsive	Soybean	a	18.5	19.0	19.1	19.2	19.7	** ¶	168
Responsive	Corn	b	2.5	2.4	2.5	2.6	2.6	NS	-
Responsive	Soybean	b	17.8	17.9	18.4	18.4	18.6	* §	65
Non-Responsive	Corn	b	3.3	3.4	3.3	3.4	3.5	NS	-
Non-Responsive	Soybean	b	19.9	20.0	20.1	20.3	20.5	*** ¶	168

* Significant at the 0.10 probability level.

** Significant at the 0.05 probability level.

*** Significant at the 0.01 probability level.

NS, nonsignificant at the 0.10 probability level.

† "a" and "b" in the year identify the first and second crop at a given location.

‡ YMR, yield maximizing rate of K fertilizer as determined by the model.

§ Linear-plateau response.

¶ Linear response (the highest K rate used by the study for the linear models).

Table 8. Soil-test K results for samples taken after the first crop and before the second crop.

Site	Crop†	Treatment (kg K ha^{-1}) 0	28	56	112	168
		mg K kg^{-1}				
1	Soybean	124	126	127	134	142
2	Soybean	122	127	132	138	141
3	Corn	109	114	117	125	146
4	Corn	162	160	160	168	172
5	Soybean	125	132	126	143	157
6	Corn	119	116	120	128	138
7	Corn	173	171	167	204	193
8	Soybean	162	165	170	175	195
9	Corn	158	162	166	179	200
10	Soybean	156	155	189	176	182
11	Soybean	151	148	160	155	167
12	Soybean	181	180	181	187	205
13	Corn	184	185	188	197	195
14	Corn	150	155	153	160	164
15	Corn	131	136	144	145	151
16	Soybean	148	145	149	157	166
17	Corn	129	132	138	142	148
18	Soybean	127	127	131	135	148
19	Soybean	103	106	109	114	108
20	Corn	120	113	110	118	110

† First-year crop (all crops were switched for the second year).

Table 9. Mean corn and soybean early growth response to K fertilization for each K treatment applied the first year of 2-year trials.

Site†	Crop	Treatment (kg K ha^{-1}) 0	28	56	112	168	Statistics	
		----------g $plant^{-1}$----------						
1a	Soybean	2.83	2.81	2.84	2.63	2.71	NS	
2a	Soybean	2.44	2.32	2.52	2.41	2.10	NS	
3a	Corn	3.07	3.55	2.90	3.51	3.39	NS	
4a	Corn	3.35	3.21	3.46	3.48	2.99	NS	
5a	Soybean	2.12	2.15	2.44	2.40	2.32	NS	
6a	Corn	2.77	2.79	2.97	3.07	3.06	*	‡
7a	Corn	0.85	0.77	0.65	0.73	0.73	NS	
8a	Soybean	0.97	0.87	0.96	0.82	0.99	NS	
9a	Corn	3.48	3.28	3.72	3.65	3.58	NS	
10a	Soybean	1.67	1.57	1.54	1.69	1.64	NS	
11a	Soybean	2.38	2.32	2.14	2.41	2.37	NS	
12a	Soybean	2.00	2.35	2.24	2.23	2.22	**	§
13a	Corn	9.53	10.60	9.90	9.92	9.39	NS	
14a	Corn	1.53	1.71	1.62	1.66	1.70	NS	
15a	Corn	3.79	4.17	4.33	4.51	4.53	**	‡
16a	Soybean	2.92	3.19	3.19	3.30	3.13	NS	
17a	Corn	3.35	3.21	3.38	3.55	3.48	NS	
18a	Soybean	1.49	1.51	1.54	1.71	1.59	*	‡
19a	Soybean	2.24	2.34	2.23	2.24	2.29	NS	
20a	Corn	3.96	4.11	4.56	4.52	4.52	**	‡
1b	Corn	5.32	5.64	5.83	5.06	5.80	NS	
2b	Corn	6.30	6.18	6.37	6.62	6.12	NS	
3b	Soybean	3.72	3.70	3.72	3.57	3.64	NS	
4b	Soybean	2.68	2.85	2.87	2.42	2.25	NS	
5b	Corn	1.54	1.80	1.80	1.98	1.82	*	§
6b	Soybean	1.98	2.07	1.92	2.03	1.95	NS	
7b	Soybean	2.92	2.88	2.85	3.04	2.79	NS	
8b	Corn	3.76	3.58	3.71	3.65	3.98	NS	
9b	Soybean	1.76	1.62	1.83	1.78	1.61	NS	
10b	Corn	4.92	5.35	5.28	5.27	5.17	NS	
11b	Corn	3.24	3.36	3.66	3.22	3.40	NS	
12b	Corn	2.54	2.50	2.47	2.44	2.58	NS	
13b	Soybean	1.32	1.40	1.43	1.42	1.44	NS	
14b	Soybean	2.54	2.67	2.88	2.92	2.58	NS	
15b	Soybean	2.53	2.37	2.31	2.41	2.60	NS	
16b	Corn	6.07	6.38	5.77	5.88	6.84	NS	
17b	Soybean	2.67	2.50	2.56	2.79	2.80	NS	
18b	Corn	2.30	2.55	2.60	2.45	2.83	*	§
19b	Corn	3.71	3.61	3.40	3.72	3.35	NS	
20b	Soybean	2.39	2.17	2.59	2.42	2.40	NS	

* Significant at the 0.10 probability level.
** Significant at the 0.05 probability level.
*** Significant at the 0.01 probability level.
NS, nonsignificant at the 0.10 probability level.
† Suffixes "a" and "b" in the site code identify the first and second crop at a given location.
‡ Linear response
§ Significant difference between control and K treatments.

Table 10. Corn and soybean early growth response to K fertilization when averaged across first and second-year grain yield responsive and non-responsive sites.

Response	Crop	Year†	Treatment (kg K ha^{-1}) 0	28	56	112	168	Statistics	YMR‡
			g plant^{-1}						kg K ha^{-1}
Responsive	Corn	a	4.40	4.82	4.70	4.79	4.67	NS	-
Responsive	Soybean	a	2.01	2.08	2.18	2.19	2.05	NS	-
Non-Responsive	Corn	a	3.01	3.02	3.11	3.24	3.11	NS	-
Non-Responsive	Soybean	a	2.17	2.18	2.15	2.18	2.19	NS	-
Responsive	Corn	b	3.14	3.33	3.35	3.33	3.31	** §	28
Responsive	Soybean	b	2.30	2.31	2.46	2.46	2.31	NS	-
Non-Responsive	Corn	b	4.80	4.86	4.83	4.73	5.07	NS	-
Non-Responsive	Soybean	b	2.52	2.47	2.51	2.49	2.45	NS	-

* Significant at the 0.10 probability level.

** Significant at the 0.05 probability level.

*** Significant at the 0.01 probability level.

NS, nonsignificant at the 0.10 probability level.

† "a" and "b" in the year identify the first and second crop at a given location.

‡ YMR, yield maximizing rate of K fertilizer as determined by the model.

§ Linear-plateau response.

Table 11. Mean corn and soybean plant K concentration response to K fertilization for each K treatment applied the first year of 2-year trials.

		Treatment (kg K ha^{-1})						
Site†	Crop	0	28	56	112	168	Statistics	
		g K kg^{-1}						
1a	Soybean	22.53	25.35	28.00	28.65	27.83	**	‡
2a	Soybean	24.75	28.48	28.93	31.70	26.98	***	‡
3a	Corn	29.53	30.55	32.28	30.68	33.05	NS	
4a	Corn	28.25	26.73	27.68	29.75	29.63	NS	
5a	Soybean	6.52	8.14	9.70	12.78	11.84	***	§
6a	Corn	12.36	15.93	17.09	22.73	26.28	***	§
7a	Corn	33.56	33.79	34.92	35.65	38.31	***	§
8a	Soybean	23.55	23.04	26.00	25.78	25.64	*	§
9a	Corn	28.43	28.18	32.73	30.04	36.60	*	§
10a	Soybean	22.99	24.59	25.61	26.33	26.03	*	§
11a	Soybean	18.85	21.53	22.03	23.28	26.58	***	§
12a	Soybean	17.26	16.30	17.63	18.99	18.37	*	§
13a	Corn	21.57	25.89	27.58	32.15	32.43	*	‡
14a	Corn	20.63	22.75	23.98	30.43	30.00	***	§
15a	Corn	16.50	19.52	22.37	23.73	24.64	***	§
16a	Soybean	22.58	21.53	23.15	23.13	21.35	NS	
17a	Corn	14.73	17.03	18.83	24.25	28.48	***	§
18a	Soybean	12.55	14.61	16.66	19.14	21.63	***	§
19a	Soybean	11.87	12.35	12.47	15.28	16.60	***	§
20a	Corn	17.88	20.35	25.19	28.38	34.25	***	§
1b	Corn	21.40	20.15	24.25	27.53	30.73	**	§
2b	Corn	22.98	22.55	23.68	32.35	32.13	***	§
3b	Soybean	17.30	18.80	18.68	18.68	20.28	NS	
4b	Soybean	11.35	11.55	11.73	10.85	12.00	NS	
5b	Corn	12.57	15.91	15.08	25.78	21.64	***	§
6b	Soybean	17.96	18.00	20.63	21.12	23.98	***	§
7b	Soybean	23.86	23.90	27.10	27.18	26.12	NS	
8b	Corn	30.13	32.48	37.08	38.50	43.30	***	§
9b	Soybean	30.10	32.73	30.65	33.63	35.35	*	§
10b	Corn	30.50	39.08	43.95	47.13	48.03	***	§
11b	Corn	14.90	16.05	16.95	17.75	23.38	***	§
12b	Corn	17.93	21.77	21.67	23.62	25.91	**	‡
13b	Soybean	17.65	18.43	18.82	20.60	19.71	*	§
14b	Soybean	15.08	15.85	17.03	21.18	21.68	***	§
15b	Soybean	15.17	18.72	17.78	19.69	21.35	***	§
16b	Corn	18.45	23.68	24.35	24.73	27.53	**	‡
17b	Soybean	14.35	14.55	15.28	17.68	18.48	**	§
18b	Corn	15.21	17.35	19.19	22.16	28.58	***	§
19b	Corn	21.38	24.78	26.24	30.86	38.24	***	§
20b	Soybean	15.55	16.89	19.23	19.79	25.09	***	§

* Significant at the 0.10 probability level.

** Significant at the 0.05 probability level.

*** Significant at the 0.01 probability level.

NS, nonsignificant at the 0.10 probability level.

† Suffixes "a" and "b" in the site code identify the first and second crop at a given location.

‡ Significant difference between control and K treatments.

§ Linear response.

Table 12. Corn and soybean plant K concentration response to K fertilization when averaged across first and second-year grain yield responsive and non-responsive sites.

			Treatment (kg K ha^{-1})						
Response	Crop	Year†	0	28	56	112	168	Statistics	YMR‡
			-------------------------------	g K kg^{-1}	-------------------------------				kg K ha^{-1}
Responsive	Corn	a	17.76	21.02	22.75	27.26	28.34	*** §	124
Responsive	Soybean	a	15.27	16.88	18.23	20.65	19.70	** §	92
Non-Responsive	Corn	a	25.39	26.10	28.60	29.79	33.39	*** ¶	168
Non-Responsive	Soybean	a	20.39	21.40	22.88	23.74	24.00	*** §	80
Responsive	Corn	b	18.91	22.63	24.28	28.74	31.97	*** ††	168
Responsive	Soybean	b	16.20	16.91	18.96	20.70	23.58	*** ¶	168
Non-Responsive	Corn	b	22.18	24.12	26.20	29.34	31.92	*** ††	168
Non-Responsive	Soybean	b	18.54	19.81	20.00	21.18	21.90	*** ††	168

* Significant at the 0.10 probability level.

** Significant at the 0.05 probability level.

*** Significant at the 0.01 probability level.

NS, nonsignificant at the 0.10 probability level.

† "a" and "b" in the year identify the first and second crop at a given location.

‡ YMR, yield maximizing rate of K fertilizer as determined by the model.

§ Linear-plateau response.

¶ Linear response (the highest K rate used by the study for linear models).

†† Quadratic response.

Table 13. Mean corn and soybean plant K uptake response to K fertilization for each K treatment applied the first year of 2-year trials.

Site†	Crop	0	28	56	112	168	Statistics	
		Treatment (kg K ha^{-1})						
		----------g K plant^{-1}----------						
1a	Soybean	0.064	0.071	0.079	0.075	0.076	NS	
2a	Soybean	0.061	0.066	0.073	0.076	0.057	***	‡
3a	Corn	0.090	0.109	0.093	0.107	0.113	*	§
4a	Corn	0.095	0.087	0.096	0.102	0.090	NS	
5a	Soybean	0.014	0.018	0.024	0.032	0.028	*	§
6a	Corn	0.034	0.045	0.051	0.069	0.080	***	§
7a	Corn	0.028	0.026	0.023	0.026	0.028	NS	
8a	Soybean	0.023	0.020	0.025	0.021	0.026	***	§
9a	Corn	0.098	0.093	0.122	0.110	0.132	*	§
10a	Soybean	0.039	0.039	0.040	0.044	0.043	NS	
11a	Soybean	0.045	0.050	0.047	0.056	0.063	**	§
12a	Soybean	0.034	0.039	0.040	0.042	0.041	**	¶
13a	Corn	0.207	0.282	0.275	0.325	0.310	*	¶
14a	Corn	0.032	0.039	0.039	0.051	0.051	*	§
15a	Corn	0.063	0.081	0.097	0.108	0.112	***	§
16a	Soybean	0.067	0.068	0.074	0.077	0.067	NS	
17a	Corn	0.050	0.054	0.064	0.086	0.099	***	§
18a	Soybean	0.019	0.022	0.026	0.033	0.035	***	§
19a	Soybean	0.027	0.029	0.028	0.034	0.038	**	§
20a	Corn	0.071	0.084	0.116	0.128	0.155	***	§
1b	Corn	0.116	0.113	0.143	0.140	0.179	*	§
2b	Corn	0.148	0.139	0.151	0.216	0.199	*	§
3b	Soybean	0.064	0.070	0.070	0.067	0.074	NS	
4b	Soybean	0.031	0.034	0.034	0.026	0.027	NS	
5b	Corn	0.019	0.029	0.028	0.051	0.040	***	§
6b	Soybean	0.036	0.038	0.040	0.043	0.047	***	§
7b	Soybean	0.070	0.069	0.077	0.082	0.073	NS	
8b	Corn	0.114	0.116	0.137	0.140	0.173	**	§
9b	Soybean	0.054	0.054	0.056	0.060	0.058	NS	
10b	Corn	0.152	0.209	0.232	0.250	0.249	**	¶
11b	Corn	0.048	0.054	0.062	0.057	0.080	***	§
12b	Corn	0.046	0.055	0.053	0.058	0.067	*	¶
13b	Soybean	0.023	0.026	0.027	0.029	0.029	*	¶
14b	Soybean	0.039	0.043	0.049	0.062	0.057	**	§
15b	Soybean	0.039	0.045	0.041	0.047	0.056	*	¶
16b	Corn	0.111	0.152	0.138	0.144	0.189	**	¶
17b	Soybean	0.038	0.037	0.039	0.049	0.052	*	§
18b	Corn	0.035	0.045	0.051	0.054	0.081	***	§
19b	Corn	0.079	0.089	0.090	0.114	0.129	***	§
20b	Soybean	0.038	0.038	0.049	0.048	0.061	**	§

* Significant at the 0.10 probability level.

** Significant at the 0.05 probability level.

*** Significant at the 0.01 probability level.

NS, nonsignificant at the 0.10 probability level.

† Suffixes "a" and "b" in the site code identify the first and second crop at a given location.

‡ Quatric response.

§ Linear response.

¶ Significant difference between control and K treatments.

Table 14. Corn and soybean plant K uptake response to K fertilization when averaged across first and second-year grain yield responsive and non-responsive sites.

			Treatment (kg K ha^{-1})						
Response	Crop	Year†	0	28	56	112	168	Statistics	YMR‡
			g K $plant^{-1}$						kg K ha^{-1}
Responsive	Corn	a	0.084	0.112	0.116	0.138	0.138	** §	142
Responsive	Soybean	a	0.032	0.036	0.040	0.046	0.040	** §	110
Non-Responsive	Corn	a	0.072	0.075	0.086	0.093	0.103	** §	168
Non-Responsive	Soybean	a	0.044	0.046	0.049	0.051	0.052	*** §	168
Responsive	Corn	b	0.067	0.085	0.092	0.105	0.116	** §	168
Responsive	Soybean	b	0.037	0.039	0.046	0.051	0.055	** §	168
Non-Responsive	Corn	b	0.107	0.115	0.124	0.139	0.161	*** ¶	168
Non-Responsive	Soybean	b	0.045	0.047	0.049	0.051	0.053	*** §	168

* Significant at the 0.10 probability level.

** Significant at the 0.05 probability level.

*** Significant at the 0.01 probability level.

NS, nonsignificant at the 0.10 probability level.

† "a" and "b" in the year identify the first and second crop at a given location.

‡ YMR, yield maximizing rate of K fertilizer as determined by the model.

§ Quadratic response.

¶ Linear response (the highest K rate used by the study for linear models).

Table 15. Mean corn and soybean leaf K concentration response to K fertilization for each K treatment applied the first year of 2-year trials.

		Treatment (kg K ha^{-1})						
Site†	Crop	0	28	56	112	168	Statistics	
		g K kg^{-1}						
1a	Soybean	20.3	21.2	19.3	23.7	23.9	*	‡
2a	Soybean	20.4	21.9	24.3	26.6	28.9	***	‡
3a	Corn	15.8	17.2	18.7	18.7	19.7	***	‡
4a	Corn	10.3	10.1	10.5	12.3	12.6	**	‡
5a	Soybean	11.0	12.5	13.3	20.5	19.5	***	‡
6a	Corn	6.0	6.7	8.1	9.3	11.3	***	‡
7a	Corn	14.1	13.6	17.0	16.4	15.9	***	‡
8a	Soybean	23.8	23.4	27.5	27.5	28.2	***	‡
9a	Corn	14.0	16.1	16.2	17.7	18.6	***	‡
10a	Soybean	20.3	24.9	22.6	24.1	26.0	***	‡
11a	Soybean	18.3	18.9	20.0	20.4	28.1	***	‡
12a	Soybean	23.2	23.5	25.2	25.5	26.2	*	‡
13a	Corn	17.0	19.2	19.0	20.9	21.7	***	‡
14a	Corn	9.7	10.9	11.0	13.8	16.5	***	‡
15a	Corn	9.8	12.1	13.0	14.3	14.7	***	‡
16a	Soybean	19.9	23.0	21.9	24.8	26.2	***	‡
17a	Corn	8.1	10.5	12.4	13.7	16.1	***	‡
18a	Soybean	14.5	16.3	18.8	18.9	22.4	***	‡
19a	Soybean	16.4	21.4	20.9	22.5	23.6	**	§
20a	Corn	11.1	13.6	16.6	17.0	19.2	***	‡
1b	Corn	10.6	10.6	12.2	12.9	13.8	**	‡
2b	Corn	10.0	10.0	11.3	12.3	12.8	**	‡
3b	Soybean	26.6	26.1	27.1	28.8	31.0	**	‡
4b	Soybean	16.0	17.6	19.7	21.0	24.5	*	‡
5b	Corn	5.7	6.7	6.2	11.1	10.1	***	‡
6b	Soybean	14.3	16.2	16.5	17.1	20.4	**	‡
7b	Soybean	27.1	27.4	29.3	28.8	27.4	NS	
8b	Corn	10.6	10.5	12.8	13.8	15.0	***	‡
9b	Soybean	21.1	20.7	21.7	25.9	26.2	***	‡
10b	Corn	12.4	15.9	17.4	18.4	17.7	***	‡
11b	Corn	10.4	10.4	10.3	11.8	13.6	**	‡
12b	Corn	-	-	-	-	-	-	
13b	Soybean	19.6	18.7	18.9	21.4	20.8	**	‡
14b	Soybean	12.0	12.3	12.9	15.1	15.7	***	‡
15b	Soybean	14.8	15.9	15.5	17.9	18.8	***	‡
16b	Corn	12.1	13.8	14.7	15.4	17.7	***	‡
17b	Soybean	14.5	16.0	18.4	20.5	25.2	***	‡
18b	Corn	7.6	8.7	9.9	11.6	13.1	***	‡
19b	Corn	11.3	13.2	13.8	14.9	16.3	***	‡
20b	Soybean	15.9	16.5	19.3	18.9	21.0	***	‡

* Significant at the 0.10 probability level.
** Significant at the 0.05 probability level.
*** Significant at the 0.01 probability level.
NS, nonsignificant at the 0.10 probability level.
† Suffixes "a" and "b" in the site code identify the first and second crop at a given location.
‡ Linear response
§ Significant difference between control and K treatments.

Table 16. Corn and soybean leaf K concentration response to K fertilization when averaged across first and second-year grain yield responsive and non-responsive sites.

			Treatment (kg K ha^{-1})						
Response	Crop	Year†	0	28	56	112	168	Statistics	YMR‡
			-----------------------------	-------g K kg^{-1}	-----------------------------				kg K ha^{-1}
Responsive	Corn	a	10.6	12.2	12.8	14.6	16.1	*** §	168
Responsive	Soybean	a	17.3	18.6	20.4	22.9	24.3	*** §	168
Non-Responsive	Corn	a	12.2	13.5	15.3	16.0	17.0	** §	168
Non-Responsive	Soybean	a	19.8	22.1	22.0	23.8	26.0	** §	168
Responsive	Corn	b	9.5	11.0	11.5	13.6	14.2	*** §	168
Responsive	Soybean	b	14.1	15.0	16.2	17.1	19.1	** §	168
Non-Responsive	Corn	b	10.8	11.2	12.7	13.6	14.8	** §	168
Non-Responsive	Soybean	b	20.0	20.3	21.5	23.5	24.8	*** §	168

* Significant at the 0.10 probability level.

** Significant at the 0.05 probability level.

*** Significant at the 0.01 probability level.

NS, nonsignificant at the 0.10 probability level.

† "a" and "b" in the year identify the first and second crop at a given location.

‡ YMR, yield maximizing rate of K fertilizer as determined by the model.

§ Quadratic response.

CHAPTER 4. GENERAL CONCLUSIONS

The overall goal of this research project was to assess the effect of soil-test potassium (STK) and fertilizer K impacts on corn and soybean grain yield, K uptake, and within-field grain yield response variation. Two different studies were conducted to achieve this general goal and several specific objectives.

One study focused on the fact that spatial variation of STK across the landscape of a field does exist, and this variation can result in differential yield responses for different parts of a given field. Studying these STK and yield response variation by using strip trials and precision agriculture technologies can aid in understanding the factors that relate to responsive and non-responsive areas within a field, and should provide data useful for improving correlations and calibrations of STK levels to yield responses. Therefore, specific objectives of this study were to use precision agriculture technologies adapted to a strip trial methodology to (1) assess the within-field variation of corn and soybean grain yield responses to K fertilization for several Iowa fields and (2) correlate the ammonium-acetate STK extractant to corn and soybean grain yield responses.

A dense grid-sampling approach (0.07 to 0.20 ha cells) was used to evaluate corn and soybean grain yield to K fertilization across fields and for within-field areas with different STK levels and soil series. The results showed that grain yield responses occurred most often in fields (or areas of fields) testing in the low interpretation classes, and the frequency of responses decreased as STK increased. The results demonstrated the value of dense soil sampling and evaluations of yield response within fields, because in several fields there was no average yield response but there were yield responses in low-testing field areas. Furthermore, analysis of yield responses for soil series within a field showed no consistent differences between soils, and the few occasions in which the yield response differed within a field the difference was explained by the average STK level or we could not find a reasonable explanation. Studying the relationships between yield response and STK based on the different data management methods showed that critical concentrations determined by the models were best for averages by site and by soil series. However, we did find, especially for soybean, that it is important to have a wide range of STK levels across many sites to provide accurate recommendations. This research has shown that the use of dense soil sampling and precision agricultural technologies can be useful to assess crop yield responses for areas of the field with differing STK level, and to further use this data in calibration research for making recommendations.

The other study was based on the recognition that grain yield responses occur most often when STK levels are low but yield responses are uncertain in the Optimum STK interpretation class and, furthermore, early growth, K concentration responses in plant tissues, and K uptake responses often occur regardless of the grain yield response. Therefore, specific objectives of the second study were to evaluate the relative magnitude of K fertilization effects on corn and soybean grain yield and both K concentration and uptake in young plants, mature leaves in summer, and grain. Conventional small-plot field trials and several K application rates were used to achieve these objectives. The results showed that grain yield responses to K fertilization were observed only when initial STK was Optimum or lower, and grain K removal responses closely followed yield. We found that in many cases, soybean grain yield, grain K concentration, and grain K removal responses to K were closely related, and occurred at many sites, however, this relationship was not observed for corn. At most sites, K fertilization seldom increased plant early growth responses, but frequently increased the K concentration of young plants and mature leaves regardless of the grain yield response. We did find that when there was a lack of response in either plant early growth or K concentration in vegetative tissues, a yield response did not occur. The results of this study showed large differences in the relative magnitude of the response to K fertilization by different corn and soybean plant parts, and that luxury uptake of K by vegetative tissues did occur at most sites.

Overall, the results of these two studies showed that plant responses to K fertilization are complex, many effects can be predicted only with large uncertainty, but knowledge was gained that should result in better K management. The study demonstrated that new technologies are very useful to improve assessment of K fertility, K fertilizer management, and crop productivity in highly variable fields. The study also demonstrated that a large amount of K absorbed early by corn and soybean often is in excess of K needed to maximize yield, have little influence on K removed with grain harvest, but would significantly affect K removal and recycling with harvest of vegetative plant parts. However, results of the project also pointed to a need for more research to better understand the factors that determine so large soil K and yield response variation within fields and the role of large K uptake by crops and how this relates to grain production.

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